PORTLAND CEMENT.

A MONOGRAPH.

BY

CHARLES D. JAMESON,

MEM. AM. SOC. C. E.

PROFESSOR OF ENGINEERING, STATE UNIVERSITY OF IOWA.

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HON. D. N. RICHARDSON,

DAVENPORT, IOWA:

DEAR SIR:

I BEG TO DEDICATE THIS MONOGRAPH TO YOU IN MEMORY OF YOUR MANY KINDNESSES TO ME DURING THE EIGHT YEARS OF MY PROFESSORSHIP IN THE STATE UNIVERSITY OF IOWA, AND TO SHOW MY APPRECIATION OF THE FACT THAT, AS A MEMBER OF THE BOARD OF REGENTS OF THE STATE UNIVERSITY OF IOWA FOR EIGHTEEN YEARS, YOU HAVE DONE MORE THAN ANY OTHER ONE MAN TO RAISE THE UNIVERSITY TO ITS PRESENT HIGH LEVEL.

RESPECTFULLY YOURS,

CHARLES D. JAMESON,

PROFESSOR OF ENGINEERING,

STATE UNIVERSITY OF IOWA.

IOWA CITY,

May 5, 1895.

PREFACE.

The following monograph is the outgrowth of a short course of lectures delivered by me each year to the Junior Engineering students of the State University of Iowa, upon Limes, Mortars and Cements. Owing to the great increase in the amount of Portland cement used and the great value it possesses as a building material, this monograph treats only of the making, testing and using of Portland cement.

The term "Portland Cement" as here used means an artificial cement made by mixing in certain known proportions, clay and chalk containing silica, alumina, iron, and carbonate of lime, and burning this mixture to the point of incipient vitrifaction and then reducing this burned product to an impalpable powder.

The term "Portland Cement" primarily means an artificial mixture. The term "Natural Portland" has very much the same meaning as natural artificial would have.

I wish to acknowledge my indebtedness to Dr. L. W. Andrews, Ph. D., Professor of Chemistry, State University of Iowa, for his kindness in writing the chapter upon the Chemical Processes, etc., page 91, and where quotations have been made from existing publications, credit has been given in a foot note.

My endeavor in writing this monograph has been to place before the engineering professsion the following essential points:

First.—In the making of Portland cement. The selection of the raw materials, their proper treatment by the different methods in general use. The burning of this material with the types of kilns used. The reduction of the clinker to cement powder and its proper storage.

Second.—In the testing of Portland cement. The requirements as set forth in the different standard specifications. Methods to be followed in the testing, and the various mechanical devices used in making the tests.

Third.—In the using of Portland cement. The comparative value of different cements. The uses of Portland cement as a material of construction. Proper methods of manipulation. Estimates of quantities and cost.

More space has been devoted to the testing and using of cement than to its making; for the reason, that, upon these two points every civil engineer should be thoroughly informed while a knowledge of the details of cement making is, from necessity, confined to a limited class of cement experts.

I venture hope that this book may prove of value not only to students in engineering, but to the engineering profession at large.

CHARLES D. JAMESON.

IOWA CITY,
May 9th, 1895.

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PORTLAND CEMENT.

A MONOGRAPH.

CHAPTER I.

GENERAL CONSIDERATIONS.

AMONG the most important of building materials may be placed *lime* and *cement*. There is very little "Engineering Construction" into which they do not enter to a greater or less extent, and their ultimate value depends more upon the manner in which they are used than is the case with most building materials.

Take wood, stone, or iron, for example, provided a good quality has been selected, nothing the constructor can do will materially affect this quality. The material may be used injudiciously, and uneconomically, but the ultimate strength remains the same. A square inch of steel will stand about the same tensile strain under all circumstances. With *limes* and *cements*, however, this is not the case. No matter how perfect the original quality of the cement may be, it may become absolutely worthless and a source of danger, if not properly handled and applied after being received.

This fact makes it of the utmost importance that, at least, all engineers should be familiar with the manufacture, use, and methods of testing limes and cements. They should know:

First.—The best and most rapid methods of testing cements, in order to ascertain the quality and characteristics of the cement received.

Second.—Knowing the quality of the cements to be used and the results to be attained, they should be familiar with the most approved methods of manipulation in order that the desired results may be attained, and attained at a minimum cost.

Third.—They should be familiar with the maximum results that may be obtained with any given type of cement.

A thorough understanding of these three points is necessary in order to make the general use of cement safe and at the same time economical. The engineer should be able to recognize a good cement when he gets it, and if it is not good, to indicate the probable reason of its failure, whether in the raw material, the method of making, or the treatment it received after the making.

Both lime and cement, when used for building purposes, are mixed with a certain amount of water and used in a more or less plastic condition. While in this plastic condition they are placed in the work in whatever position or form is required and then this mixture hardens with more or less rapidity.

This hardening is called *setting*, and it is this property of setting under different conditions that forms one of the radical differences between limes and cements.

Lime Mortar will only set when exposed to the action of the air, and therefore can only be used in layers so thin that the air can penetrate to all parts of it. All parts of this lime mortar must not only be accessible to the air, but to insure setting the air must be dry.

Where lime mortar has been used in cellars that are damp and in the plastering of houses exposed to the damp sea winds its absorption of moisture has been so great that it never has become thoroughly set, and is always more or less damp and soft. With cement and cement mortar this is not the case.

A mixture of cement and water, properly made, will not only set in the open air, but will set when immersed in water

or when in a vacuum. That is, contact with the air is not necessary, in order that the process of setting may take place. In fact, not only is contact with the air *not* necessary for the setting of cement, but in order that the maximum results may be reached, all cement mortar should be kept either wet or immersed until it has become thoroughly set.

This may be considered as one of the most important rules governing the use of cement, viz:

The quality of any cement work is very materially improved by keeping it wet during the process of setting. Some idea can be formed of the amount of the improvement due to keeping the work wet, by a study of the diagrams in Chapter IX. From this fact, that contact with the air is not necessary for the proper setting of cement, it is evident that there is almost no limit to the mass of cement mortar or concrete that can be used. No matter how massive the structure may be, and no matter in what thickness the cement mortar or concrete may have been used, if the proper materials have been properly manipulated, this mass will set thoroughly throughout. Therefore while lime can only be used in a dry location and in thin layers, cement can be used in any location and in any quantities.

Lime mortar under the best of circumstances has very little strength, either of adhesion or cohesion, while the best Portland cements properly used attain a strength superior to that of any of the building stones, with the exception of some granites, quartzites, and trap.

The chemical changes and reactions that take place during the process of setting, in either lime or cement, are not, apparently, well understood, as much conflict of opinion exists among chemists upon this question. In Chapter VI. by Launcelot Andrews, Ph. D., F. C. S., will be found the results of the most recent chemical researches upon the question.

The general differences between limes and cements, from an engineering standpoint may, therefore, be taken as lying in the fact that limes will set only in contact with dry air while for the setting of cement, not only is the presence of

dry air not necessary but the best results obtain when the cement is kept wet or immersed in water.

There can be no sharp line drawn between limes and cements, although there is no difficulty in distinguishing at sight between pure lime and good cements.

The ordinary lime of commerce consists of the calcined carbonate of lime in a state of greater or less purity.

The constituents of cement are carbonate of lime, silica, and alumina with iron, with a few other ingredients of more or less importance. These three, carbonate of lime, silica, and alumina, with iron, however, are the most important, and are always present in varying proportions. It is the relative proportions in which these constituents are mixed that make the resulting cement more or less hydraulic, that is, the power of setting under water, as the hydraulicity of the resulting compound varies as the percentage of the ingredients vary. We have cementing compounds from pure lime at one end of the list to Portland cement at the other. They can be divided into the following three classes: **Lime, Hydraulic Lime,** and **Cement.**

Lime consists of practically pure carbonate of lime with less than 10 % of impurities.

Hydraulic Lime has mixed with the lime from 10 to 25 % of silica, alumina and iron.

Cement contains:

Lime, - - -	55 to 65 %
Silica, - - -	18 to 24 %
Alumina and iron, -	8 to 14 %

These usually amount to 94 or 96 % of the whole. The balance may be made up of magnesia, alkalies, and sulphuric anhydride. These last are present in minute quantities, and although they undoubtedly have some influence upon the qualities of the cement, still this effect is very slight.

Lime.—Lime is made by the simple calcination of more or less pure carbonate of lime. This is found as limestone in all parts of the world. The calcination is done usually in a kiln

of a form of construction shown in Fig. 1. The fuel most commonly used is wood, but either soft coal or coke may be used. The method of charging the kiln is as follows: A rough open arch is built of limestone above the bottom of the kiln. Upon this is placed a layer of fuel, then a layer of limestone, a layer of fuel, and so on, alternately, to the top of the kiln. The layers of fuel grow less as the top is approached. The fire is started at the bottom, and the temperature gradually increases. As the fuel is consumed the limestone drops towards the bottom, and more fuel and limestone is added at the top. As rapidly as the limestone becomes sufficiently burned it is removed from the bottom of the kiln. It comes from the kiln in hard, white, rock-like pieces.

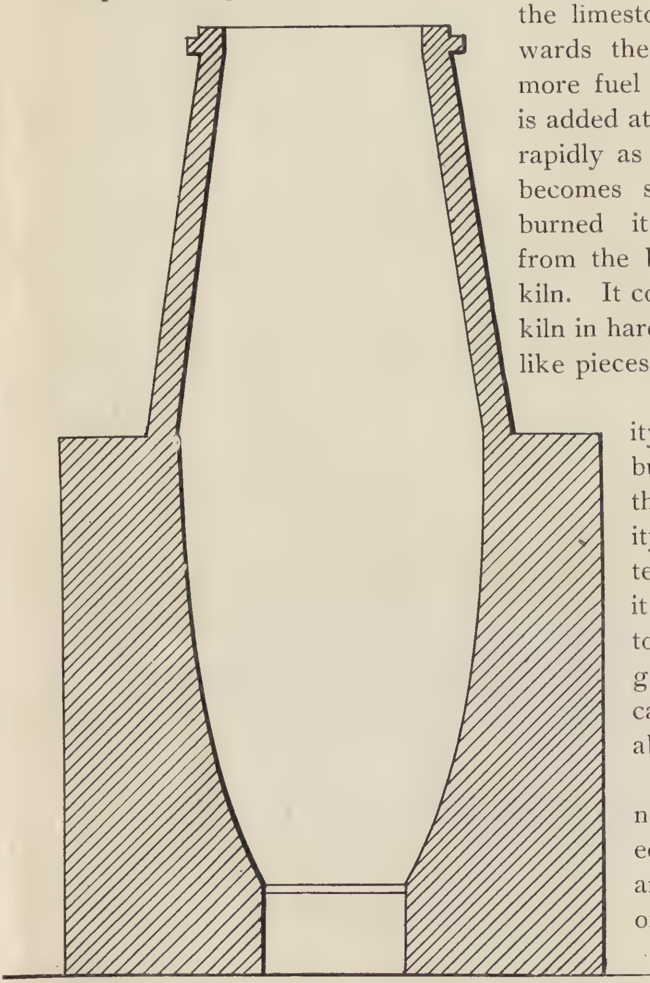

FIG. 1.

One peculiarity of the freshly burned lime is the great avidity it has for water, and, when it is exposed to moisture, the great amount of carbon it will absorb.

Lime that has not been exposed to moisture, and is in more or less the same condition in

which it came from the kiln, is called *Quicklime.* When this lime has been exposed to moisture in any shape, and allowed to absorb as much as possible, it is called **Slaked Lime.**

All lime, before being used, must be slaked. This can be done by Drowning, Sprinkling, or exposure to the air.

Drowning.—The quicklime is spread out in a water-tight box and water added until it is completely covered. The entire amount of water needed should be put in at once. When the water is added the temperature rises, the mass effervesces, the quicklime increases rapidly in bulk, slowly disintegrates, and finally falls to pieces in a fine white powder, soluble in water. The impurities are separated from the lime. If additional water is added after the process of slaking has commenced the temperature is lowered and the slaking is not done as thoroughly as it otherwise would be. After the water has been added it is a good plan to cover the box so as to retain the heat as much as possible.

The increase in bulk due to slaking is 200 or 300 %. The lime, after the slaking is complete, is run off through an opening in one end of the box. It is about the consistency of very thick cream. The opening is covered with a grating or netting to prevent the passage of hard lumps, etc. The slaked lime is run either into another box or into an excavation in the ground, this second box or excavation being many times larger than the slaking box. The slaked lime soon becomes a stiff paste, and should be covered with sand or boards. It should not be used for mortar for a number of days, usually about 10, until it has become thoroughly cool.

Slaking by Sprinkling.—The quick lime is spread out in a layer 6 or 8 inches in thickness, and thoroughly sprinkled with water. It slowly disintegrates and falls into powder. There is no great increase in the temperature, and no effervescence takes place. One drawback to this method is the space and time required, which are both much greater than is required for *Drowning*, and there is no reliable data to show that the lime thus slaked is in any way improved.

Air Slaking.—The lime is spread in layers 4 to 6 inches

thick, and exposed to the air. It must be turned a number of times in order to insure thorough exposure to the air. The time and space required are both very great and the gain, if any, small. Thoroughly slaked lime paste can be put up in air-tight casks and kept without deteriorating for almost any length of time.

HYDRAULIC LIME.

Hydraulic Lime is made by the simple calcination of limestone that contains anywhere from 10 to 25 per cent. of the requisite impurities. The temperature required for calcination is but slightly higher than that needed for the burning of quicklime. The material must be slaked the same as quicklime before it can be used, and is reduced to powder in this way. No grinding machinery for reduction is used. The slaking is much slower than is the case with quicklime and as the proportion of impurities increase it becomes slower and slower, until at last a point is reached where the resulting substance passes from hydraulic lime to natural cement. The reduction must be done by grinding and the hydraulicity becomes a prominent characteristic.

Cement.—Cement as used in an engineering sense means such a combination of lime, silica, alumina and iron, that when properly calcined, reduced to powder, and gauged with a proper amount of water has the property of setting under water and in places where it is not exposed to the action of the air. It also has the property of setting when in contact with the air.

For good results to obtain, the proportion of the requisite constituents must be within certain narrow and well-defined limits. These proportion have already been given.

The cements used in building construction can be divided into two general classes.

NATURAL CEMENT.

ARTIFICIAL OR PORTLAND CEMENTS.

In what follows the term *Portland cement* means always an artificial cement as distinguished from natural cement.

Natural Cements.—In many parts of this country and Europe, there have been found immense deposits of impure limestone, that contain with more or less accuracy the necessary constituents for the making of cement. These constituents have been mixed by nature and for cement making must be used in the proportions found.

The actual proportions do not usually conform with that required for the best cement, but the extreme cheapness at which this cement can be put upon the market renders it a most valuable addition to the materials of construction. The natural cement does not in any way compete with the Portlands, but it has done much to raise the standard of masonry construction, from the fact, that its small cost allows of its use in many places where lime was used before.

The difference between the natural and Portland cements as to the raw materials used is this:

The *desirable* constituents in each are the same.

In making natural cements, some impure limestone that contains as nearly as may be the correct proportions of lime, silica, and alumina is used, and the value of the resulting cement depends upon the correctness with which nature has mixed these ingredients. It is found good, bad and indifferent.

With the raw material for Portland cement, however, nothing is left to chance. It is known, within certain narrow limits, what the constituents should be, and in what proportions they should be present. This being known, such materials are used as contain these constituents in a more or less pure state, and then these comparatively pure raw materials are mechanically mixed in the correct proportions.

The mere fact that the raw materials are nearly perfect does not insure good cement, as the best of raw material may be rendered useless by improper burning or grinding. But, on the other hand, no good cement is possible unless the raw materials are good. Of course any mechanical mixture of lime, silica, alumina, etc., within the limits named, will give good Portland cement if properly burned and ground. But in selecting raw material there is one other, most important, question that must be considered, viz., that of cost.

In order to make a perfect mechanical mixture the materials must be reduced to an impalpable powder. The harder the materials, the more expensive this is; consequently, in selecting the raw material, the question of the cost of reduction must be considered.

The advantages of Portland cement over natural cement are two, viz.:

1st. The Portland cement is much better *per se.* The best natural cement never attains the hardness nor has the strength or durability of the most ordinary Portland.

2nd. Where proper care is used, Portland cement of any one brand possesses a uniformity of quality that can never be attained in the making of natural cement.

Examine almost any stone quarry, and the impossibility of obtaining a uniform quality of stone in any quantity will be seen at once. The quality of the stone varies in different parts of the quarry and in different layers of the stone, no two layers containing the same chemical constituents. As the stone is used in the condition in which it comes from the quarry, it will be seen that there will be an unavoidable variation in the quality of the resulting cements.

With Portland cement this is different. The raw materials are practically pure, and after experiments have given the proportions of mixing and the subsequent methods of treatment, there is no excuse for any irregularity in the results.

This uniformity in results is the one great point to be worked for in cement making. It can only be accomplished by the exercise of the greatest care in the selection and treatment of the raw materials. In the process of making there are some radical differences between natural and Portland cements. In the calcination the natural cements require a temperature but little above that required for lime burning, while the Portland cements require a temperature just short of that required for vitrification. The mixing, grinding, etc., all increase the cost of the Portland until at last the finished product brings about $3.00 per barrel on the market, while the natural cement sells for 50 cents.

True economy in the choice of cements consists in using the one best adapted for the work in hand. When the work is such as to justify the increased expense on account of required durability or strength, then the best Portlands should be used. But on less important work or masonry of a cheaper character, the natural cements should be used. Nothing has done more to improve the character of all masonry work during the last twenty-five years, than the cheapness and excellency of these light-burned natural cements.

CHAPTER II.

HISTORICAL DATA.

THE use of some cementing substance for building purposes runs back into the darkness of pre-historic times. We have the record of no age of the world in which some form of cement has not been used. At the very earliest periods of history, not only was cement in some form used, but the proper methods of manipulation were well understood. One of the earliest writers upon engineering construction, whose writings are now available, was Marcus Vitruvius Pollio who, as an architect, engineer, and author, worked under the patronage of the Roman Emperor Augustus. No better idea can be obtained of the advanced knowledge upon limes and cements at that age of the world than by making some abstracts from the Works of Vitruvius. We wish to call particular attention to the line of reasoning by which the action of lime, etc., are accounted for.

"Having treated of the different sorts of sand, we proceed "to an explanation of the nature of lime—which is burned "from either white stone or flint. That which is of a close "and hard texture is better for building walls, and that which "is more porous is better for plastering when slaked for "making mortar, if pit sand be used, three parts of sand to one "of lime. If river or sea sand, then two parts of sand to one "of lime. . . . . . *If to river or sea sand, potsherds

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*The gain in quality due to mixing finely ground burned clay with lime appears to have been well known.

"ground and passed through a sieve, in the proportion of one-"third part, be added the mortar will be better for use. The "cause of the mass becoming solid, when sand and water are "added to the lime appears to be, that stones, like other "bodies, are a compound of elements: those which contain a "large quantity of air being soft, those which have a greater "proportion of water being tough, of earth hard, of fire "brittle. For stones which, when burnt, would make excel-"lent lime, if pounded and mixed with sand without burning, "would neither bind the work, nor set hard; but having "passed through the kiln, and having lost the property of their "former tenacity by the action of intense heat, their adhesive-"ness being exhausted, the pores are left open and inactive. "The moisture and air which were in the body of the stone, "having therefore been extracted and exhausted, the heat "being partially retained, when the substance is immersed in "water before the heat can be dissipated, it acquires strength "by the water rushing into all its pores, effervesces, and at "last the heat is excluded. Hence limestone, previous to its "burning, is much heavier than it is after it has passed "through the kiln; for, though equal in bulk, it is known, by "the abstraction of the moisture it previously contained, to "lose one-third of its weight by the process. The pores of "limestone, being thus opened, it more easily takes up the "sand mixed with it, and adheres thereto; and hence in dry-"ing, binds the stones together, by which sound work is "obtained."

The use of Pozzolana was well understood and its cementing qualities were accounted for in the same manner as that first given for limes. Although we have no written records, still we know that lime was used by the Egyptians, thousands of years before the Christian Era, and we have very fair evidence that they, also, understood the mixing of clay with the lime and thus making a crude form of Portland cement.

But leaving the ages of antiquarian uncertainty and coming down to the times of modern civilization, we find that as late as 1757 nothing reliable was known upon the manufacture

and use of hydraulic cements. Up to that time the purer the limestone the better the lime for constructive purposes. Neither hydraulic lime nor cement was known. In 1757 Smeaton, the engineer in charge of the rebuilding of the Eddystone Lighthouse, commenced his experiments upon the various obtainable materials for making mortars. The structure was of such vast importance and the strength required so great that Smeaton, not satisfied with the action of the mortars in general use, commenced experiments to determine the constituents necessary in a cement that would set under water and under salt water.*

Smeaton was the first to break down the tradition that the purest and hardest limestone was the best, at least for hydraulic purposes, and the first to prove that a proper mixture of carbonate of lime and clay was what gave the best results. He was the first to discover that this calcined mixture of clay and carbonate of lime was the real cause of hydraulicity. The Eddystone Lighthouse stands to-day, not only as a guide to "ships that pass in the night," but also as a monument to mark the starting point in all that we know concerning hydraulic cements.

From 1757 until about 1824 very little advance was made in cement making and no advance was made in our knowledge of cements beyond that left by Smeaton. A patent dated December 15th, 1824, was granted to John Aspdin, of Leeds, bricklayer, for the manufacture of Portland cement. Edgar Dobbs, of Southwark, was granted a patent for a Portland cement mixture in 1810. Maurice St. Leger, of Camberwell, was granted a similar patent in May, 1818. These last two patents expressly state in their specifications that the material was *not* to be subjected to sufficient heat for vitrification. All experimenters in Europe appeared satisfied with producing hydraulic lime, with the exception of Aspdin. He soon discovered the advantages of incipient vitrification and produced Portland cement. Cement works were slowly established,

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*The student should by all means read Smiles' Life of John Smeaton.

but owing to the uncertainty in the character of the product, and the great fight against the new cement, by the well-established makers of Roman cement* the industry languished and barely lived for many years.

The manufacture of Portland cement in Germany was commenced in 1852, near Stettin. In 1855 the first Stettin Portland cement works were erected; in 1877 there were, in Germany, thirty large cement works. The German works, at first, copied the English methods, but now their methods are widely different. In 1892, in Germany, there were sixty-two large Portland cement factories and the production for that year was ten million six hundred thousand barrels. Besides these there are also ninety-six smaller factories, the production of which is not given.†

The largest Portland cement works in France are at Boulogne. The product equals in character either the German or the English.

The first Portland cement works in this country were established in 1875. Its manufacture has been carried on to the greatest extent near Allentown and Egypt, Pennsylvania. There are factories at Bellefontaine, Ohio; South Bend, Indiana; Warner's, New York; and the latest and one of the best at Yankton, South Dakota.

Saylor's Portland cement, made at Allentown, has the best established reputation and has been much used. The Buckeye, of Bellefontaine, Ohio, has given as high results in laboratory tests as any cement tested by the author. The Western Portland cement, of Yankton, South Dakota, has only been on the market a few years, but thus far it has given results, both in the laboratory and in actual work, that have never been excelled by either German or English Portland cements. In the United States by far the greater part of the hydraulic cement used is of the light-burned natural cement. The Rosendale type, made in Ulster county, New York, supplies

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*Roman cement is similar to our light-burned natural cement.

†From Trans. Am. Soc. C. E., Vol. XXX., No. 1, Gary on Cement.

nearly one-half the demand for this cement. Louisville, Kentucky, Utica, Illinois, and Milwaukee, Wisconsin, are the centers of production of this type of cement in the west.

In 1889 there was imported into this country 650,000 barrels of Portland cement and 150,000 barrels were made here. The same year 4,200,000 barrels of natural cement was made in this country.

CHAPTER III.

MANUFACTURE OF PORTLAND CEMENT.

One of the first things to be decided upon in establishing a Portland cement manufactory is the selection of the raw materials necessary. The constituents necessary in the cement making materials are lime, silica, alumina, and iron, and for the making of the cement the additional item of fuel.

The necessary carbonate of lime can be found in the shape of limestone in almost any locality. But as this must be reduced to a fine powder during the first stage of cement making, the ordinary limestone is too hard to make this possible with the necessary economy. Therefore the softest and purest limestones are usually the only ones used. This is found in the shape of chalk and in all degrees of hardness and purity. The softer it is the more cheaply it can be worked, and the purer it is the more uniformity there is in the resulting cement. There are immense deposits of this material in this country, and consequently no necessity as yet of using any of the harder and more expensive varieties.

Those deposits that have been worked with good results are: One running south through New York state, and visible at numerous points through Pennsylvania and Virginia. One most excellent deposit, that is worked at Bellefontaine, Ohio, from which the Buckeye Portland cement is made. One that is worked at South Bend, Indiana; and in the middle west, a deposit of almost pure chalk, that, starting north of the Canada line, runs down the valley of the Missouri on the western border of Iowa, and keeping south, can be traced

into Louisiana and Texas. From that point to about half way to the City of Mexico the author has no knowledge of this deposit, but, beginning at a point about one hundred miles north of Leon, Mexico, there is a good supply of chalk to the Isthmus of Panama. On the Pacific coast there is an almost unlimited amount of good material, that as yet is very little worked. The Missouri belt of chalk is worked at Yankton, South Dakota, and no better cement making materials can be found than at this point, both from a chemical and economical stand-point.

The carbonate of lime, then, should be the softest and purest that can be found, other things being equal.

The silica, alumina and iron are usually found in the shape of clay. The clay is usually dark blue and to a certain extent indurated. It is usually of such a softness that it may be removed with a pick, but of such a hardness that the use of some low grade explosive is often economical. About sixty per cent. of the clay should be silica. But it must be remembered in selecting clay that this silica must be in a state of chemical combination and not in the shape of sand. This is a point that has sometimes been neglected with deleterious results. The chemist in analyzing clay for cement making must remember that the sand in the clay must not enter into his estimate as to the amount of silica available for cement making, and clay containing as little sand as possible should be used.

If in the preparation of the raw materials the treatment of the clay was such that any sand present was reduced to an impalpable powder, then the sand might act in the required way as silica, but as no such methods are used, the sand becomes a distinct foreign element that is detrimental to the manufacture of good cement. Fortunately for cement makers in this country, the chalk and clay necessary for cement making are often or usually found in contiguous layers. Such an arrangement does much to lessen the cost of production.

The cost of the fuel that is to be used for the burning of the cement is the one other item of raw material that must be

considered. Therefore as to the quality of the cement, the chalk and clay must be very carefully tested, and not only tested in the beginning as to their general suitability, but tested day by day as the work goes on. Each separate layer in the quarries should be tested and the correct proportions to be used determined.

Given suitable clay and chalk, with correct subsequent treatment, and the cement will be good and uniform. The cost of producing the cement will depend upon the character of the clay and chalk and the cost of the fuel.

The value of the cement to the makers will be the price at which it can be sold and this will depend upon the cost of transportation to an available market. These various questions will decide within certain limits, the location of the works.

As to the relative financial importance of the raw material and fuel. The carbonate of lime is usually about three times that of the clay by weight. The amount of fuel necessary runs from 10 to 20 per cent. of the weight of the raw material. The resulting cement is about 60 per cent. of the weight of the chalk and clay. The weight of the fuel entirely disappears during the process of manufacture.

From this data we can make a fair estimate of the best location for the works, when the raw materials are separated.

Cheap transportation to market is necessary for the ultimate success of the enterprise and whenever possible the works should be so located as to make water transportation available.

There is one more point to be considered in connection with the reduction of the raw material, viz.: the material used should always be that, that can be reduced to a powder with the least expense—provided the other qualities are equal. Chalk and clay usually fulfill this condition of cheap reduction and are therefore most generally used. But when such material cannot be obtained and harder working material must be used, such as crystalline limestone or slate, it is still possible to reduce such material to powder by means of modern grinding machinery. The increased cost due to this is not so great but that a large profit remains when the product sells at the ordinary market rates.

In the early days of the manufacture of Portland cement, some of the makers in England were compelled to use a limestone in the place of chalk, and in order to use this they resorted to what is known as the *Double Calcination Process*. That is, the limestone was first burned to lime, the lime slaked, and then this paste or powder mixed with the clay and the whole burned to a clinker. This process is very little practiced now, owing to the great improvements in the modern machinery of reduction. Whatever process is used the result should be that the raw materials are reduced to exceedingly fine powder and thoroughly mixed.

After the location of the works has been decided upon, the next thing is the designing of the works themselves. This should be done by an engineer who is perfectly familiar with the entire process of cement making. The whole should be carefully studied out and reduced to paper before any construction is begun. As much of the process of manufacture as possible should be done by gravity. If the raw material is so located as to permit, the works should be located below the level of the quarries.

The quarries are on the highest level. The preparation of the raw material next. Drying floors, plates, and kilns next. Reduction of clinker next. Storage, packing, and shipping on the lowest level. It is rare that such an ideal arrangement as this can be made, but such an arrangement should be borne in mind, and other things being equal, the works made to conform to it as nearly as possible.

Reduction of Raw Material.—The method to be employed in the reduction of *Raw Material*, for the making of Portland cement, depends entirely upon the character of the material used.

The object of any method used is, however, the reduction of the *Raw Material* to an impalpable powder, and the intimate mechanical mixture of these powders in the correct proportions. The processes in general use can be divided into two classes.

The Wet Process and the Dry Process.—In nearly every

case, however, some modification or combination of these processes is used.

THE "WET PROCESS."

The raw materials, to which this process is suited, consist of some form of clay and chalk of such a character as to be nearly soluble in water. The material is taken from the quarries and by means of crushers or grinders reduced to a coarse powder.

In some cases where the material is easily acted upon by water, it is not passed through any crusher or grinder, but simply used in the form in which it comes from the quarry. Whatever preparatory method may be used, however, the material when in proper condition is put into water.

As this is the point where the two materials clay and chalk are mixed, much care must be exercised.

A careful chemical examination of each material must be made, the correct proportions decided upon, and then care must be taken that these proportions are used. The materials, in the correct proportions, are then put into some variety of wash mill or mixing machine, with a great quantity of water.

In some cases each ingredient is put into the mill separately and the entire mixing done there. While in there the dry raw materials are more or less mixed before any water is added.

A simple method for partial mixing is to spread the material in layers upon a floor, the two materials alternating and the thickness of the layers being proportional to the relative amount of each material needed. There are six or eight of these layers in a pile. The material is removed from the pile to the mixing machines by means of barrows, and the man in loading the barrows, cuts through all the layers with his spade. In this way the material becomes quite thoroughly mixed before the mixing machine is reached.

The Wash Mill.—The construction of the wash mill will be understood by an examination of Figs. 2 and 3.* There is a

*These figures and the descriptions are taken from "Portland Cement: its Manufacture and Uses," by Henry Reed, pp. 208 and 209.

great variety of these mills. The earliest form is shown in Fig. 2. There is a circular trough of masonry about 20 feet in diameter and 6 or 7 feet deep. In the center of this is a masonry pier, which has on it a fixed sole-plate and socket,

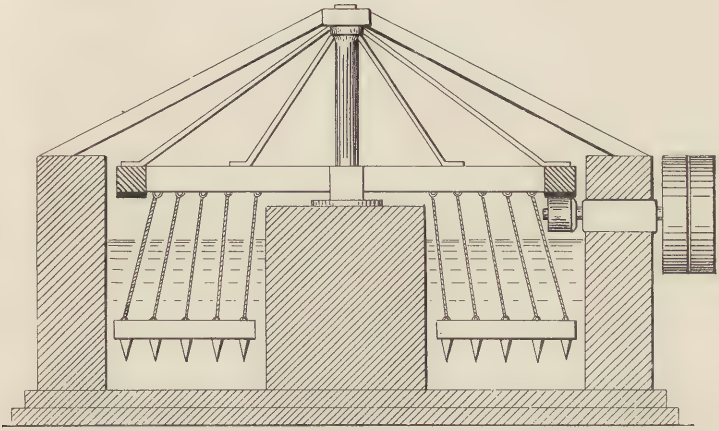

FIG. 2.

that receives the toe of a vertical shaft. From this shaft is supported a circular rim of wood that has a rack on the under side. This rack is driven by a pinion, as shown in Fig. 2. There are a number of arms extending from the center to

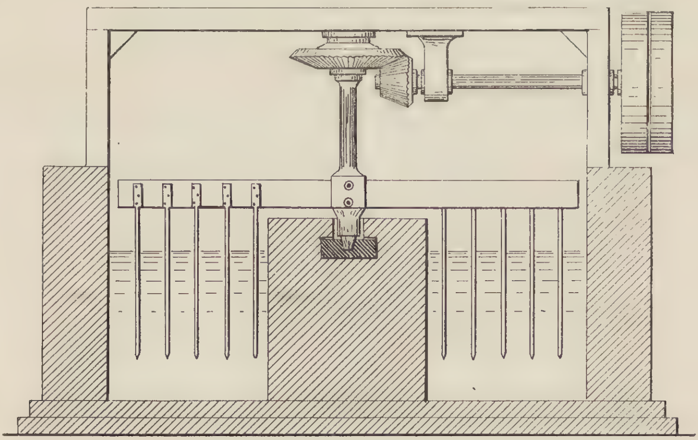

FIG. 3.

this wooden wheel, and from these arms are suspended, by chains, harrows. The cement making material is put into the trough with a great surplus of water, and a rotary motion given to the wooden wheel. The harrows are thus dragged through the material and water, and the material thoroughly amalgamated.

A more modern form is shown in Fig. 3, where a bar is substituted for the horizontal wheel. This bar being driven by gearing at the center, long knives, bolted firmly to this bar, are substituted for the harrows.

A mill of the size given is driven at about 20 revolutions per minute. The correct speed in any case, however, must be determined by the character of the material and the relative amount of water used.

In some manufactories they make a practice of double-working the material. That is, it is thoroughly worked in one mill, and then transferred to another, more water added, and the amalgamation completed. In modern practice this is not usually necessary. The process of working the material in the wash mill is as follows: In the first place, only such material can be used in this process as will become thoroughly disintegrated by water and can be held in suspension by it in a finely divided state. The material is reduced by crushers and triturators to the necessary degree of fineness and put into the wash mill in the correct proportions. This correctness of proportions is one of great importance, and one to which too much attention cannot be given. Without this correctness the resulting cement will be inferior or useless. Sufficient water is admitted to the trough to hold the entire mass in suspension with ease. For the proper mixing of the materials too much water cannot be used. The only limit is the amount of water supply and the length of time necessary for getting rid of the water in "backs," or settling reservoirs. For economy, the least amount of water that will thoroughly accomplish the disintegration and amalgamation should be used; and this can only be decided upon by experiment. Different materials require different amounts of water.

When the water has been admitted, the wash mill is started and the whole mass thoroughly agitated.

The raw material must become so finely divided that it is held in suspension and almost in solution by the water. The amount of water is increased and an overflow opened. This overflow allows the liquid to escape into a sluice. It flows along this sluice until it empties into the "backs."

In order to guard as much as possible against the introduction of sand into the ultimate mixture, the following arrangement is usually made:

At different points in the sluices or chutes, there are depressions or cavities, and in these cavities the movement of the liquid is much less rapid than in the chute. The sand having a much greater specific gravity than the finely divided clay and chalk, settles to the bottom of these cavities and is retained there. In this manner a portion of any sand present is prevented from passing into the "backs."

The best method however, to prevent sand from being present in the cement mixture is to use a clay that contains as little sand in it as possible. No matter what precautions are taken to prevent it, some sand will get into the "backs" if there is any in the clay used, and the more sand in the cement mixture the poorer will be the quality of the cement produced.

The principle upon which the wash mill is worked is, that the materials are reduced to such a finely divided state, in such an abundance of water, that they are practically in solution and when they have been sufficiently agitated to bring about this result, the liquid is run off into "backs" or settling reservoirs and the cement material allowed to settle.

There are some disadvantages connected with this process. The clay and chalk being of different specific gravities there is a possible danger that however well they may have been mixed in the wash mill, they may to some extent become separated in passing through the sluices. Even if they reach the "backs" in the correct proportions, there is danger that they may settle unevenly and in layers.

The only way in which this can be guarded against is a

careful testing of the material from time to time, as the work goes on. The "backs" require a great deal of floor space and in some localities would either be the cause of great expense or prohibit the use of the "Wet Process" in its entirety.

When such is the case, however, there are modifications of this process that eliminate many of its disadvantages, without destroying its utility.

Another drawback to the continued use of the simple "Wet Process" is the length of time required before the raw material is ready for the kilns. Often two or three months are required to get rid of the water in the backs. The material must settle and the water be carefully drawn off from the top.

When the material has finally settled and as much water has been drawn off as possible, the remainder of the water is removed by evaporation, until the "slurry" has stiffened to a degree that it can be handled well with a shovel. It is then broken up in pieces and taken to the drying floors, where it is thoroughly dried by artificial heat, usually the escaping heat from the kilns. All of this takes many weeks and necessitates the carrying of an immense amount of raw material.

In the "Dry Process" this loss of time is eliminated and in some works the amount of prepared raw material on hand is never more than one day's supply. This, of course, is attained at an increase in the cost of preparation. Modifications and combinations of the "Wet" and "Dry" systems are used in order to modify the evils of each.

THE "DRY PROCESS."

In 1852 the Germans began to turn their attention to the manufacture of the "Patent English Portland Cement." They had no raw materials available, similar to the chalk and clay. But there was an abundance of suitable limestone and highly indurated shale. The "Wet Process," or reduction by water, was entirely out of the question, and this fact led to the inauguration of the so-called "Dry Process." The raw materials are reduced by purely mechanical means. Taken

from the quarries, they are passed through ordinary stone crushers and reduced to the size of macadam, 2 or 2½ inches as a maximum. This crushed material is then passed through another form of crusher, called a triturator, that reduces it to the size of coffee beans. It is then reduced to a flour by means of some form of grinding machine. These grinding machines are of three general types, the vertical runner, the ball pulverizers and the horizontal millstones.

Up to the point of being ground the two materials are usually reduced separately. At this point they can be economically mixed in the correct proportions and ground together. In this manner an accurate and thorough mixing of the two ingredients is accomplished.

The dry powder is now slightly dampened and run through a brick machine. The bricks thus formed are dried thoroughly by artificial heat, and are ready for burning. But a few hours' time is necessary to dry the bricks, and but comparatively little storage space is required.

The material having been made into bricks under considerable pressure, the mass is compact and dense, and burns with much less uniformity than the dried slurry from the "backs."

The raw material is taken from the quarry, crushed, ground, made into bricks, dried, burned, ground to cement, and sold, in much less time than is occupied by the material in the "backs" by the "Wet Process."

All of this, however, is accomplished at a great increase in cost, and there are many points in this process that need careful watching.

In order that the result may be of the best, most accurate and thorough grinding is necessary. This is the point at which the extra expense is incurred. It is an absolute necessity that the materials should be reduced to impalpability and unless it is done in the grinding it is not done at all. With modern machinery and the experience of the last fifty years there are but very few cement works that use either the "Dry" or "Wet Process," but usually some modification suited to the special character of the raw material.

Semi-Wet.—In the preparation of the raw material by means of the wash mill the following modification of the "Wet Process" is often used.

The material in the mill is mixed with much less water than in the "wet." The mixing is done as thoroughly as possible and then the slurry removed from the mill, not by an overflow, but by conduit near the bottom. This conduit conducts the slurry to two millstones between which it is thoroughly ground. The advantage of this process is that there is much less water in the prepared slurry and consequently less time is required for drying.

Another modification that is used in this country is as follows:

The material is quarried and crushed to a coarse powder. It is then thrown into a large mixing machine with a great surplus of water. The machine is started and the contents thoroughly amalgamated. The whole mass is then lifted to a higher level by pumps and run off through sluices to the drying floor.

Mixing Machine.—The mixing machine consists of a boiler plate cylinder about 15 feet in diameter and 15 feet in length. Inside of this is a rotating mixer driven by steam or water power. Cement works of any size will need a number of these machines. The slurry is run out over the drying floors in layers about 4 inches thick. When sufficiently hardened it is cut into bricks about 1 foot square. This is done either by a man using a specially formed spade or by means of a harrow with cutting blades, that is drawn across the slurry in two directions, at right angles with each other. When these bricks have sufficiently dried they are turned up on edge and finally taken to the drying rooms and the drying completed by artificial heat. They are then either placed in the kiln for burning or stored away for future use.

Pug-Mill.—The material may be reduced and mixed with just sufficient water to make stiff mud. It is then driven through a pug-mill, which completes the mixing, and is cut into bricks as it issues from the pug-mill. These bricks require but little time to dry.

These are only a few of the most important methods used for the preparation of the raw material. All the methods in actual use are some modification or combination of the "Wet" and "Dry Process." The method that should be used at any one locality must depend upon the character of the material, its resistance to reduction, the water supply, the available ground space, and the question of the value of time.

These questions can only be answered correctly by an expert in cement making, and such should be employed in designing the works. The result that must be attained, in order to produce good cement, is that the raw material shall be reduced to minute fineness and that the mechanical mixture of the different raw materials used must be practically perfect.

Burning Cement.—The raw material must be properly reduced, proportioned, and intimately mixed. When this is done it is made into bricks or blocks, dried, and is then ready for the burning.

Upon the well doing of this depends the quality of the cement, as well as upon any of the previous steps in cement making, but no more. Unless the preparation of the raw material has been properly attended to, no amount of correct burning can make good cement, and, further, no amount of good burning can make good cement unless the treatment of the cement after burning is properly done.

The accurate performance of each of the three stages is necessary for the production of good cement.

There are three well-defined periods in cement burning:

First, the driving off of all the water that remains in the slurry.

Second, the driving off of the carbonic acid.

Third, the fusing together of the silica, lime, alumina, and iron.

These different periods occur in the order given here, and each requires a different temperature for its proper accomplishment.

Before the making of Portland cement, all lime and cement burners had lived in constant dread of over-burning their

material, and even after a good idea had been formed of the constituents necessary for Portland cement, still it was many years before any one realized what an increase in temperature was needed to give the best result in the cement.

For the making of the best possible cement from given materials, the materials must be burned just as near to the point of actual vitrifaction as is possible without reaching it. If this point is passed, the cement is over-burned, and the amount it deteriorates on account of this depends upon how much it is over-burned.

The particles that are perfectly vitrified have no more cementitious properties than so much powdered glass.

There is this trouble about over-burned cement. Its color is good, possibly a trifle lighter, and its weight is increased, therefore it cannot always be distinguished by the eye from cement that is very good. For many years an increase in weight was looked upon as an improvement in the quality of the cement. Up to a certain point this was true, but beyond this point it was not. The more cement is burned, the more it weighs, and as distinguished from the light-burned any increase in weight marks an improvement in the quality, but when the point of vitrifaction is passed, the weight still increases, while the quality deteriorates. Therefore, in any specifications where the weight is to be specified, care must be taken that the required weight is not reached by over-burning.

The color of Portland cement is a light bluish gray, and it can be readily distinguished from the various colors of the light-burned natural cements.

The color of the different natural cements runs from a light yellow through all shades of yellow and chocolate browns to almost black. The color depending upon the material from which it is made.

Kilns.—There are two types of kiln in more or less general use and a great number of patent kilns that are not suited for general use. A few of these are suited for use under special conditions, and many, as far as the author can find out, are of no use whatever.

Dome Kiln.—The earliest type of kiln used for cement burning was what is known as the dome kiln. The general form is shown in Fig. 4. This form of kiln is still in more general use than any other.

The relative height and width of these kilns have been changed and rechanged many times during the last sixty years of Portland cement burning and possibly some of the details changed, but in all of its essential features it remains unchanged. The process of using this kiln is as follows:

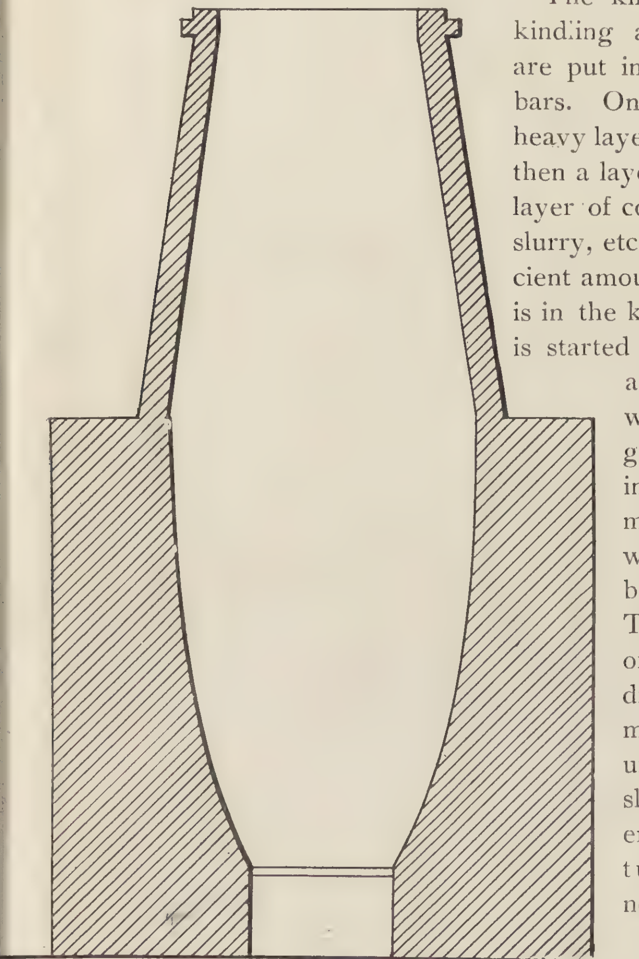

Fig. 4.

The kiln being cold, kindling and light fuel are put in on the grate bars. On top of this a heavy layer of coal, and then a layer of slurry, a layer of coal, a layer of slurry, etc., until a sufficient amount of material is in the kiln. The fire is started at the bottom and burns upward, slowly, gradually heating the whole mass. The kiln warms up, and becomes hot. The first action of the heat is to drive any remaining moisture from the slurry. A moderate temperature only is needed for this. As more fuel

ignites and the fire approaches the slurry, the temperature increases until it begins to act upon the carbonic acid. During the first stage there is a visible vapor being driven off. This ceases when the mass has become thoroughly heated to a good red heat, and the carbonic acid begins to be driven off. The amount of carbonic acid that must be driven off is enormous, amounting often to 30 or 35 per cent. of the weight of the cement material. When this has been accomplished and the whole mass raised to a white heat, the third and last stage begins, that is the fusing together of the cement making materials. At this point is reached the uncertainty of cement burning.

The product may be under-burned, over-burned or correctly burned, and which of these results is attained depends upon the proportionment of fuel and slurry. The relative amounts of each must be decided upon before the firing begins, and when once decided upon cannot be in any way changed. As the fuel is consumed the clinker sinks to the bottom and is removed, fresh fuel and slurry being added at the top. In this way the kiln can be made more or less continuous. Under other circumstances the kiln is charged and the entire mass burned, then the kiln allowed to cool and the clinker removed. The disadvantages connected with the kiln are as follows:

The relative amount of fuel must be decided upon before the burning commences and once the kiln is started the amount of fuel cannot be in any way changed. The relative amount of fuel necessary depends upon the character of the fuel, the character of the slurry, the shape and height of the kiln, the temperature, the humidity of the atmosphere, and the direction and force of the wind. As will be seen many of these conditions are entirely beyond the control of the cement maker and are conditions that are liable to change at any time during the burning.

There is an enormous waste of fuel that goes off with the carbonic acid.

Many attempts have been made to utilize this wasted heat

by heating with it, the drying rooms, etc. Some of these applications have been more or less successful, and some have not. The one thing that should never be lost sight of in all of these schemes for utilizing this waste heat, is that the main object of the kiln and the fuel it consumes is to burn the cement, and not to heat the drying floors, and care must be taken that, in thus attempting to utilize the waste heat, the work of the kiln as a kiln is not lowered.

The clinker as it comes from the kiln is sorted; the thoroughly well-burned taken to the crusher and grinders, and the under-burned put to one side to be reburned. This re-burning is sometimes done in the same kiln, but at some works they have smaller kilns for this purpose. None but properly burned clinker should be passed on to the grinders.

We have thus drawn attention to some of the salient features of the dome kiln and some of the principal disadvantages connected with its use, and these disadvantages become more emphasized when it is used as an intermittent kiln, that is, when charged cold, heated up, and then allowed to cool off after each charge is burned. When this is done, there is the immense loss of heat in reheating the kiln each time, together with the unavoidable loss of time.

In addition to all of this, there is the expense of repairing the lining of the kiln after each charge, the heating and cooling causing the lining to crack and break.

The Hoffman Ring Kiln.—Soon after the manufacture of Portland cement began in Germany the manifold disadvantages attending the use of the dome kiln became evident, and an effort was made at once to substitute some more economical and improved type. This soon led to the invention of the Hoffman Ring Kiln, shown in section Fig. 5 and in plan Fig. 6. The essential features of this type of kiln, as can be seen from the figures, are as follows:

There is one large central chimney, and around this is built a series of compartments. These compartments are connected directly with a smoke chamber by means of flues. This smoke chamber is annular in shape, and surrounds the base of the

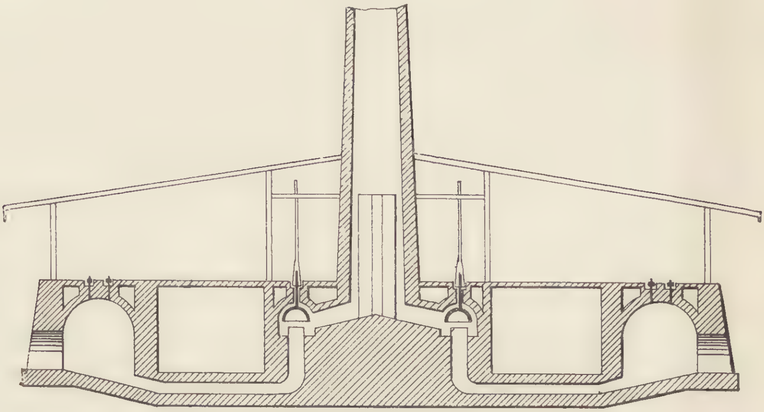

Fig. 5.

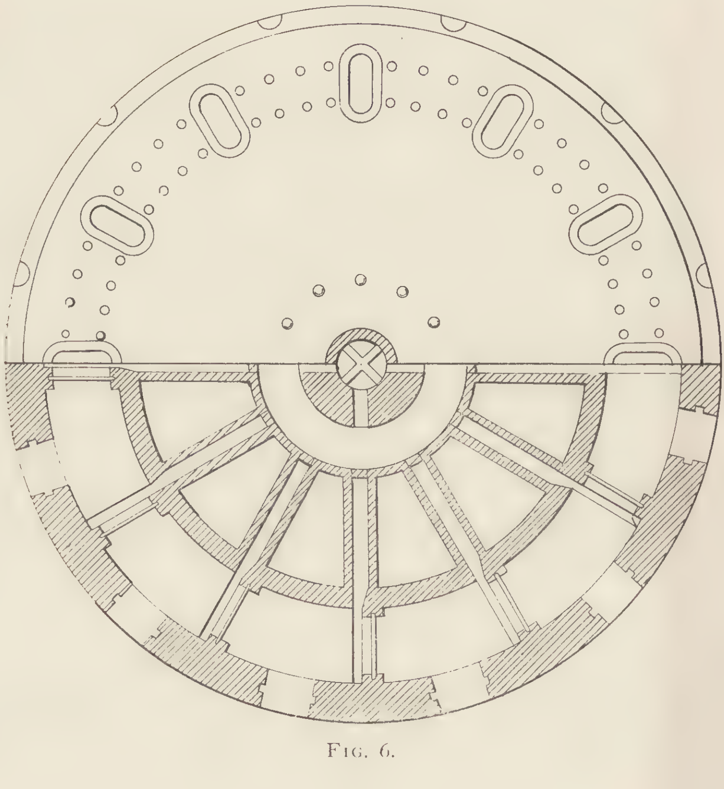

Fig. 6.

chimney. The draft through these flues can be regulated by means of valvular dampers that are worked from the outside. The outside compartments are separated from each other by means of sliding doors or partitions that may be opened or shut at will. Each of these compartments has an opening on the outside, through which the cement material is introduced, and through which the process of burning can be watched. The fuel is put in through openings at the top. The arrangements are perfect for the admission of the requisite amount of fresh air, in order to complete the combustion.

The kiln shown, Figs. 5 and 6, is a "down draft" kiln. That is, the fire is at the top and the heat is drawn down through the cement material and passes out through the flue at the bottom. In some of these "ring" kilns the fire is on the outside and near the bottom, and the opening of the flue near the top. This, however, is a mere detail. In whatever part of the compartment the fire and fuel are placed, the object is the same, namely: that the heat shall be distributed with uniformity through the entire compartment, and that the combustion shall be as nearly perfect as possible.

The method of operating the kiln is as follows: the material to be burned is placed in the compartments. The fire in one compartment is started, the heat carried directly to the chimney. The compartment begins to warm up. All the moisture is driven from the cement making material. The heat increases, and the carbonic acid is acted upon. Now the heat, instead of being carried directly to the chimney, is turned to one side and passed through one, two, or three adjacent chambers. It warms up these chambers and drives off the moisture. In this way all the heat is utilized. When more heat is required in these adjacent chambers a fire in each one of them is started. These fires serve to complete the cement burning and the waste heat is passed along through other compartments in order to be utilized. As the material in any compartment becomes thoroughly burned, the fire is allowed to die out, and cool air is admitted in order to hasten the cooling of the material. This cement material, in

the condition in which it comes from the kiln, is called *clinker*. As soon as the material has become sufficiently cool it is removed from the kiln and fresh material put in. The chamber has not been allowed to cool sufficiently to cause much injury to the lining by contraction. When the fresh material is in place, the heat from some adjacent chamber is turned through it, eventually its own fire is started, and so the process is made continuous.

The material to be burned is preferably in the shape of pressed bricks rather than that of merely dried slurry. The bricks having been subjected to a certain amount of pressure, in the making, are firm, and retain their form better, during the burning, than dried slurry. There is, possibly, a slight increase in the amount of fuel required to complete the burning, but this is more than compensated for by the absence of any danger of "dusting."

The advantages of using bricks instead of dried slurry are the same when a dome kiln is used as with a Hoffman kiln.

By the term "dusting" is meant the disintegration or falling apart of the cement material during the process of burning. When this happens in a dome kiln the draft is stopped and further burning becomes impossible.

In placing the bricks in a Hoffman kiln, they should be so piled as to allow of the heat being drawn through every part of the chamber.

The advantages attending the use of the Hoffman Ring Kiln, or kilns of a similar type, are as follows:

The saving in the amount of fuel is from 10 to 20 per cent. owing to the possibility of the continued use of the heat from one chamber to another. Also from the fact that the arrangement of flues is such that the combustion is much more perfect than is ever possible with a dome kiln, and also for the reason that the kiln is never cooled down below a certain point and thus the amount of fuel that is required to warm up the dome kiln is saved, after the ring kiln is once started. In the Hoffman the fire is entirely under control. The burning of the cement material can be watched and the

amount of heat acting upon it increased or decreased at will. From this fact there exists no excuse for not having the cement burned to exactly the right point.

There need be no uncertainty and no rule-of-thumb as to the amount of fuel needed. Each stage of the burning is under full control the whole time. Nothing is left to chance. There are some drawbacks attending the use of the continuous ring kiln. In order to make it an economical kiln it is necessary to keep it running as a continuous kiln. That is, keep it running for a season or a considerable length of time. When not run as a continuous kiln, but in an intermittent manner, it is by far more expensive than the dome kiln. There is another very serious difficulty that is met with in the continuous running of these kilns. The finding of some suitable material for the lining of the cement chambers. This difficulty arises, not so much from the fact that the temperature to which the lining is exposed is so exceedingly high, but that the lime in the cement material combines with the silica and alumina in the fire-brick lining and causes them to flux and mix with the slurry. For this reason the intermittent kilns are still much used, notwithstanding the very serious defects that exist in them. The heat to which the lining of these intermittent kilns is subjected is not so great as that in a continuous kiln.

There have been a great number of kilns designed of the continuous ring type. But in order to secure a patent upon any of these designs it was necessary to depart more or less from the design of the original Hoffman kiln, and, almost without exception, it has been found that the excellency of the kilns is diminished just exactly as the original details are departed from. There are a number of special types of kilns designed for cement burning that deserve short descriptions: None of these are in general use, and probably even the best of them would not be found economical if used upon a large scale. Still the first to be described possesses some positive merits in itself, while the last two are at least ingenious in their conception.

The Bock Tunnel Kiln.—This form of kiln has been used with more less success in places where it was necessary to burn a certain limited amount of cement and of making the first cost of the plant as little as possible.

The general design of the kiln will be understood by an examination of Figs. 7, 8, 9. The tunnel is built of brick and lined with fire-brick, with a 2-inch air space between the lining and the outside. The cross-section of the tunnel may vary to suit the work that it is expected to do. Where only a moderate temperature is required, such as is needed for the burning of common brick and lime, a square section with a flat arch for a roof, will answer the purpose. Where the product is to be Portland cement or paving brick it will be found better to give a certain amount of batter to the sides, with a deeper arch for the top.

The chimney is built at one end of the tunnel, and usually at the feeding end. The material to be burned is run in on trucks that are fastened together in such a manner as to make them practically one long truck. Each of these trucks is loaded with about 500 brick or their equivalent in cement material. The fire boxes are on top in the kilns built for burning lime and ordinary brick. But when cement is to be burned the boxes on top have been found not to be sufficient, and additional fire boxes with gratings have been introduced on each side. The tunnel is practically divided into two separate compartments, the one above the other. The manner in which this is accomplished is shown in Fig. 8. The platforms of the trucks project until they nearly reach the sides of the tunnel. Directly under this platform and running the full length of the tunnel on each side, is an iron trough, Fig. 9. This trough is filled with sand. From the edge of the platforms is an iron lip that projects downward into this sand, By this arrangement all communication between the upper and lower part of the tunnel is cut off. The track and running gear of the trucks are in the lower portion of the tunnel, and the fire, with the material to be burned, in the upper portion.

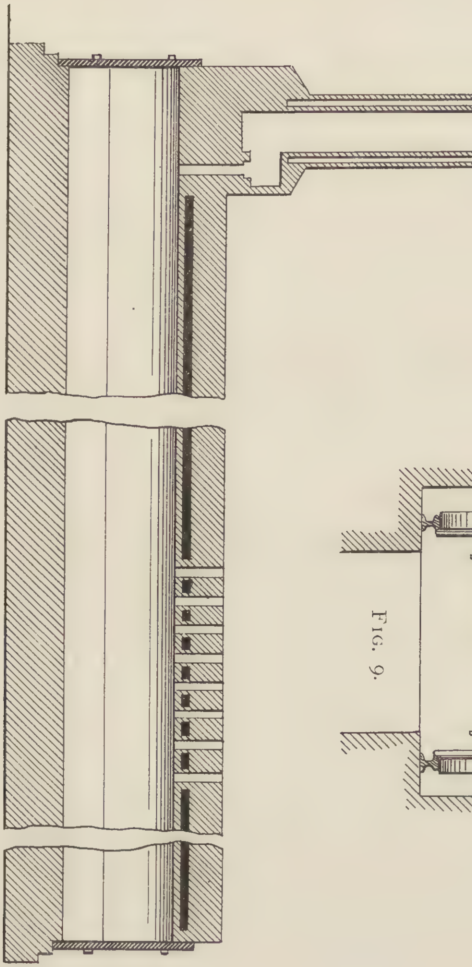

Fig. 7.

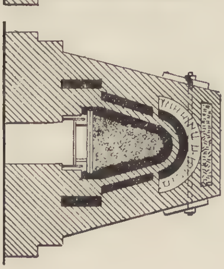

Fig. 8.

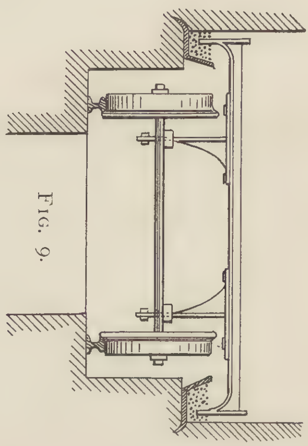

Fig. 9.

Fresh air is admitted to the lower portion at the chimney end. This air passes along under the trucks and assists in keeping everything relatively cool. At the other end of the tunnel it passes around and up over the end of the truck, and returns to the chimney through the material that is being burned. In this manner the proper amount of air is furnished for combustion. By means of proper dampers, etc., the amount of air admitted is regulated to that required. The material being burned may be watched during the whole process, and the amount of fuel increased or decreased, as necessary.

The trucks are constructed principally of wrought-iron, the platform being covered with fire-brick, laid in fire-clay. The running gear is lubricated with a preparation of graphite.

The trucks after being loaded with the raw material are forced into the tunnel by means of a hydraulic press or an endless screw worked by steam.

The capacity of the kiln is almost without limit, as it depends upon the length of the tunnel or upon the number of them. As yet these kilns have not been used in this country, so far as the author is aware, but in France and Germany they have been used to a considerable extent in the burning of brick and to a slight extent in the burning of cement.

The cost of one of these kilns of a capacity capable of burning 8,000 bricks per day is about 2,000 to 2,500 dollars and the number of brick required for construction about 140,000. The price would include track and trucks.

In the kiln just described the kiln is a tunnel and the raw material is loaded on trucks and placed in it. There is another type of tunnel kiln, as it might be described. In this case the tunnel is a wrought-iron tube or cylinder that has a slight inclination with the horizontal.

This cylinder is made to revolve upon its longitudinal axis. It is set in a fire box and the whole apparatus so designed that the cylinder may be heated to a white heat, or almost any other temperature required, and made to revolve at any required speed. The raw material is reduced to the requisite

degree of fineness, and the different ingredients then most thoroughly and intimately mixed. This dry powder is introduced into the upper end of the white hot cylinder. The cylinder is slowly revolved, and the fine dust is slowly moved down and along the cylinder until it comes out of the lower end burned. The speed with which it passes through the cylinder is determined by the inclination of the cylinder, the speed with which it revolves, and the amount of burned cement powder that can be turned out per hour depends upon the temperature at which the cylinder is held. This type of kiln has some interesting features. It has never been used in this country, but the principle upon which it is based might well repay a careful investigation.

There is still another type of experimental kiln that, although it has never been used on a large scale as far as the author knows, still it may not be without merit. In the last described kiln we had a metal cylinder surrounded by fire, the cement making material passing through the cylinder. In the type now under consideration, the tube is heated to a white heat by the burning of gas on the inside. The raw material is tempered with water. The heated cylinder is fixed horizontally in a trough, in such a manner that it can be revolved. The trough is filled with the slurry, to a point just beyond where it touches the cylinder.

As the heated cylinder revolves a thin coating of slurry adheres to it and at some point of the revolution this thin coating is removed by a scraper. The temperature of the cylinder is supposed to be sufficient to thoroughly burn the slurry into clinker before it is scraped off.

Grinding.—After the cement has been thoroughly burned, the clinker is removed from the kiln and sorted. Only the well-burned clinker is taken to be ground. That portion that is under-burned is placed by itself to be reburned, and the over-burned is rejected. As soon as the sorting has been completed, the well-burned clinker is removed to be ground to powder. The clinker is first passed through some type of crusher, similar to those described in Chapter VII. In this

manner it is reduced to the size of coffee grains, and is then reduced to powder by means of millstones. Nothing yet has been devised that will do the work as well and as cheaply as properly dressed millstones.

The necessity of reducing the clinker to flour and of doing this as cheaply as possible has led to the designing of a countless variety of mills. The two types upon which the most work has been done are what are known as edge runners, and the ball mills. Of these two the ball mills are giving the most satisfaction.

There is this peculiarity in regard to the grinding of cement. The mere fact that it is fine does not satisfy the necessary conditions. It must be floury. Two cements may have the requisite degree of fineness and still one of them be all grit and the other all flour. The more floury the cement is, the better will be the results obtained with it. As yet there has been no grinding machine invented that for an equal amount of grinding will produce such a large per centage of flour as the ordinary millstones.

In regard to the amount of power consumed in grinding cement by each of the above principles, the following table is taken from "Faija on Portland Cement," Trans. Am. Soc. C. E., October, 1893, p. 59:

Millstones,	30 to 32 I. H. P. per ton per hour.
Ball mills,	16 to 18 I. H. P. " " " "
Edge runner,	12 to 14 I. H. P. " " " "

In each case the cement was ground to about a fineness of 5 % residue on 2,500-mesh sieve.

Sifting.—In order to insure a uniformity of fineness, some makers have all the cement sifted as it comes from the stones. The residue on the sieves is thrown back and reground.

The sifting of the cement is in itself a most excellent idea. But care must be exercised, that the workmen do not make this subsequent sifting an excuse for careless grinding, and thus necessitate the regrinding of a large per cent. of the output.

Storing.—After the cement has been ground it should be stored in suitable store-rooms for a number of days at least.

Very little Portland cement is at its best immediately after being ground, and under the remarks upon the testing of cements we have noted some of the peculiarities of the cement in this respect. The cement should be stored in perfectly dry and well ventilated store-houses. It should be spread out in layers of 6 to 10 inches deep. These layers can be turned when desired and thus the beneficial effect of storage hastened to some extent.

Most cement makers do not seem to realize the great advantages that would obtain by the having of large and suitable store-houses. Not only would the quality of the cement be improved but, with large store-room space, the works could run even when the market was temporarily dull.

Packing.—When the cement has become thoroughly cool or is to be forwarded to the market, it is packed in barrels or sacks. The barrels are lined with water-proof paper, in order to protect the cement from moisture. When the cement is to be used at once, it is usually packed in sacks. These sacks are either of paper or burlap. The paper is the cheaper and is also preferable, as better preserving the cement. The weight of a barrel of Portland cement is about 400 pounds, gross. The sacks are of such a size that they hold ¼ or ⅓ as much cement as a barrel.

CHAPTER IV.

TESTING CEMENTS.

In carrying on any work of construction in which cement forms an important factor, it is of the utmost importance that the engineer should know exactly what class of cement he is using and what degree of excellency he may expect to obtain.

In order to obtain this information with a reasonable degree of accuracy some method of testing the cement is necessary. What these methods shall be is still a mooted question among the users of cements, and one upon which a great diversity of opinion obtains.

The following are the usual characteristics for which cement is tested, viz.:

Tensile Strength, Compressive Strength, Fineness, Setting Cross Strain, Adhesion, Cracking, and Checking.

Tensile Strength.—The most usual method of testing the quality of cement is by means of tension. The neat cement, or any desired proportions of cement and sand, is mixed with sufficient water to make a very stiff paste. This paste is molded into briquettes, and after a certain lapse of time these briquettes are pulled apart, and the number of pounds' strain necessary to do this is recorded. The shape of the briquette and the details of manipulation are fully described later.

This is the most usual test for cement.

In actual work cement is never used in such a manner as to

subject it to a tensile strain, and the reason that it is subjected to tensile strain in testing is simply one of convenience.

Tension can be applied to a briquette with more facility and uniformity than compression. Any irregularity in the making of the briquette can be more nearly equalized in the testing machine.

The apparatus necessary for these tests can be very easily improvised at a small cost. They occupy little space, and can be readily moved from place.

The objections to tests by crushing are:

1st. With any reasonable amount of care in the preparation of the specimens and the carrying on the tests, the results are most variable and uncertain.

In order to make these results of value, much care and much skill is necessary in the preparation of the specimens to be tested. The size of all the specimens to be tested must be exactly the same. It is not enough that we know the dimensions of the different specimens. In order that correct comparative results may obtain, these specimens must all be of the same dimensions. There is very little known as to the actual effect of increasing the size of a specimen to be subjected to compression. Take a specimen one inch square and two inches long, it will take a certain number of pounds to crush it.

Take a specimen of the same material, four inches long and two inches square, that is containing four square inches of crushing area. It will be found that the required crushing force will be much greater than four times the amount required to crush the first specimen, or the resistance to crushing per square inch is greater in the larger specimen than in the smaller. A more unequal result may be obtained if the length of the specimen in proportion to its sectional area is varied. From this can be seen the necessity of absolute uniformity in the size of the specimens to be tested.

This requirement does not exist to such a degree in tension tests.

Another great drawback to compression tests is the fact that in order to make the results of value the ends of the

specimens must be parallel and at right angles to the sides. In order to insure this, it is necessary that each specimen to be tested should be ground with special apparatus and great care.

In order to get any satisfactory results, even when all the above conditions have been complied with, it is necessary to make the specimens of such a size that the ordinary cement testing machines are not powerful enough to crush them, and a larger and much more expensive machine is needed.

For these reasons and others, can be seen the objections of requiring the compressive test, in any series of standard tests, and this notwithstanding the fact that cement is usually used in compression.

Fineness.—Cement is usually tested to ascertain the degree of fineness to which it is ground. The quality of any cement is improved by fine grinding. The degree to which this should be carried is a mere question of cost.

The finer the cement is ground, the better it is in quality, but also the greater the cost of manufacture, until at last a point is reached where any greater increase in fineness costs more than it improves the quality of the cement. The grinding should stop just before this point is reached.

It is perhaps needless to say that in most cements the grinding stops much before this point is reached. The test for fineness is to pass the cement through a sieve of 10,000 meshes to the inch. That is 100 wires to the lineal inch. The wires are what are known as No. 40 Stub's Gauge.

The amount of cement to be passed through the sieve is carefully weighed and then that portion weighed that is left on the sieve. Thus the so-called per centage of fineness is obtained. A cement that will all pass through a sieve of 625 meshes per square inch, and only leaves 4 or 5 % on a sieve of 2,500 meshes per square inch, is, for practical purposes, fine enough.

The cement that is to be made into briquettes and pats must not be sifted, unless for special reasons, but must be used exactly as it comes from the barrel. In case good results are not obtained by the tests made with the cement as

taken from the barrels, then some of the cement should be sifted, and briquettes made of that portion that passes the sieve. A comparison of the results obtained with the cement sifted and unsifted will show how much the quality of the cement would be improved by finer grinding.

Form of Briquette.—Fig. 10 shows the form of the briquette that was recommended by the American Society of Civil Engineers and has since become the standard form in this country. The weakest section, as will be seen, is at the center. The briquette is one inch thick and at the smallest section is just one inch across, giving a breaking area of one square inch. This breaking section is much smaller than that used in England or on the Continent. It was adopted by the American Society of Civil Engineers because of the fact that it was found to be sufficiently large to give good results, while its smallness rendered it much easier to make the briquettes of a uniform density throughout, with a freedom from air bubbles.

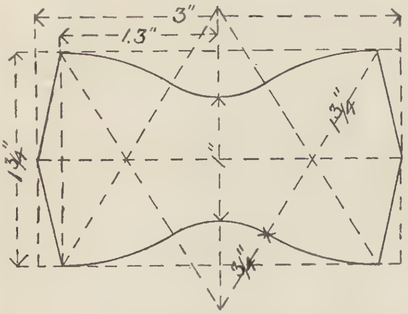

FIG. 10.

The Making of Briquettes.—Briquettes for testing cement are made in two ways, by hand and by machine. When made by hand, the mortar is made of the right consistency and pressed into molds by means of a small trowel. The briquette is left in the mold until sufficiently set to allow of being handled. When only a few briquettes are to be made, and all of these made by one person, the hand molds answer the purpose. There is always this disadvantage attending their use: the mortar being placed in the molds by hand and pressed down with a trowel, it is almost impossible to give the same amount of pressure to each briquette, and the personal equation of the maker becomes a very prominent feature in the briquettes, and when these briquettes are made

by two or more persons satisfactory results are almost impossible.

Let two or more persons make a number of briquettes from the same lot of cement, with the same proportions of water and in apparently the same manner, and when these briquettes are broken there will be a marked variation in the results obtained from each lot. This variation is often so marked as to materially vitiate the result.

Molds.—The form of the molds used for hand-made briquettes is shown in Figs. 11, 12, 13. The material is usually gun-metal or some other alloy of copper that is sufficiently hard and does not become rusted by exposure to moisture. The molds are made in two pieces in order to facilitate the removal of the briquette. When in use the two parts are held together by means of a spring, as shown in Fig. 14, or by clamp, as shown in Fig. 15.

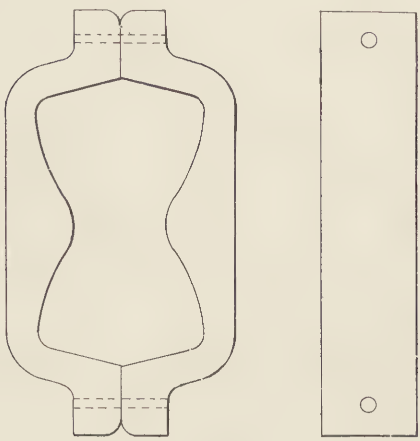

Fig. 11.

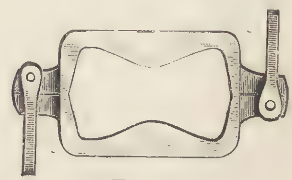

Fig. 12.

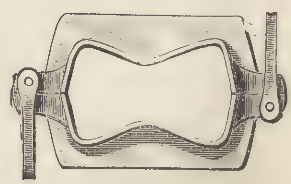

Fig. 13.

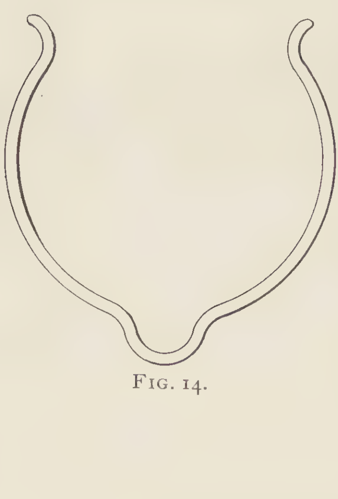

Fig. 14.

Briquette Machines.—The evils attending the use of hand-made

briquettes have been already mentioned, and numerous attempts have been made to so modify these methods as to insure a greater uniformity in results obtained from briquettes made from the same cement. All the work done for this purpose has been along the line of obtaining uniformity in the pressure applied to the cement during the making of the briquette.

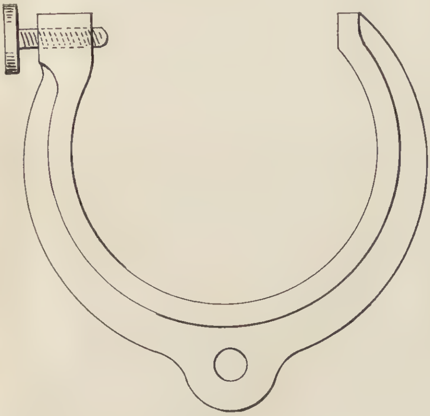

Fig. 15.

The Böhme Hammer.—In Germany the standard briquettes are made with the "Böhme Hammer apparatus," Fig. 16.*

The apparatus consists of a tilt hammer with automatic action.

"The hammer is driven by a cam wheel of 10 cams actuated "by simple gearing. The wrought-iron handle of the hammer "is let into the cross-head which carries the axle of the ham- "mer, and keyed to this cross-head and to the cap, so that "it may be readily replaced if worn. The steel hammer "weighing 4½ pound, is similarly fastened to the cap. As "soon as the intended number of blows has been delivered, "the mechanism is automatically checked, the proper setting "have been made for this purpose before beginning the work.

"The number of blows required in the German Standard "tests is 150. The forms to receive the mortar consist of a "lower and upper case held together by springs. The lower "case for compression specimens consists of two angle-irons "held on a plane plate by a grinding strip and a screw acting "on the latter. Upward motion is prevented by two wedge-

*The following description is taken from the Trans. Am. Soc. C. E., Oct., 1893. "Gary on Testing of Portland Cement."

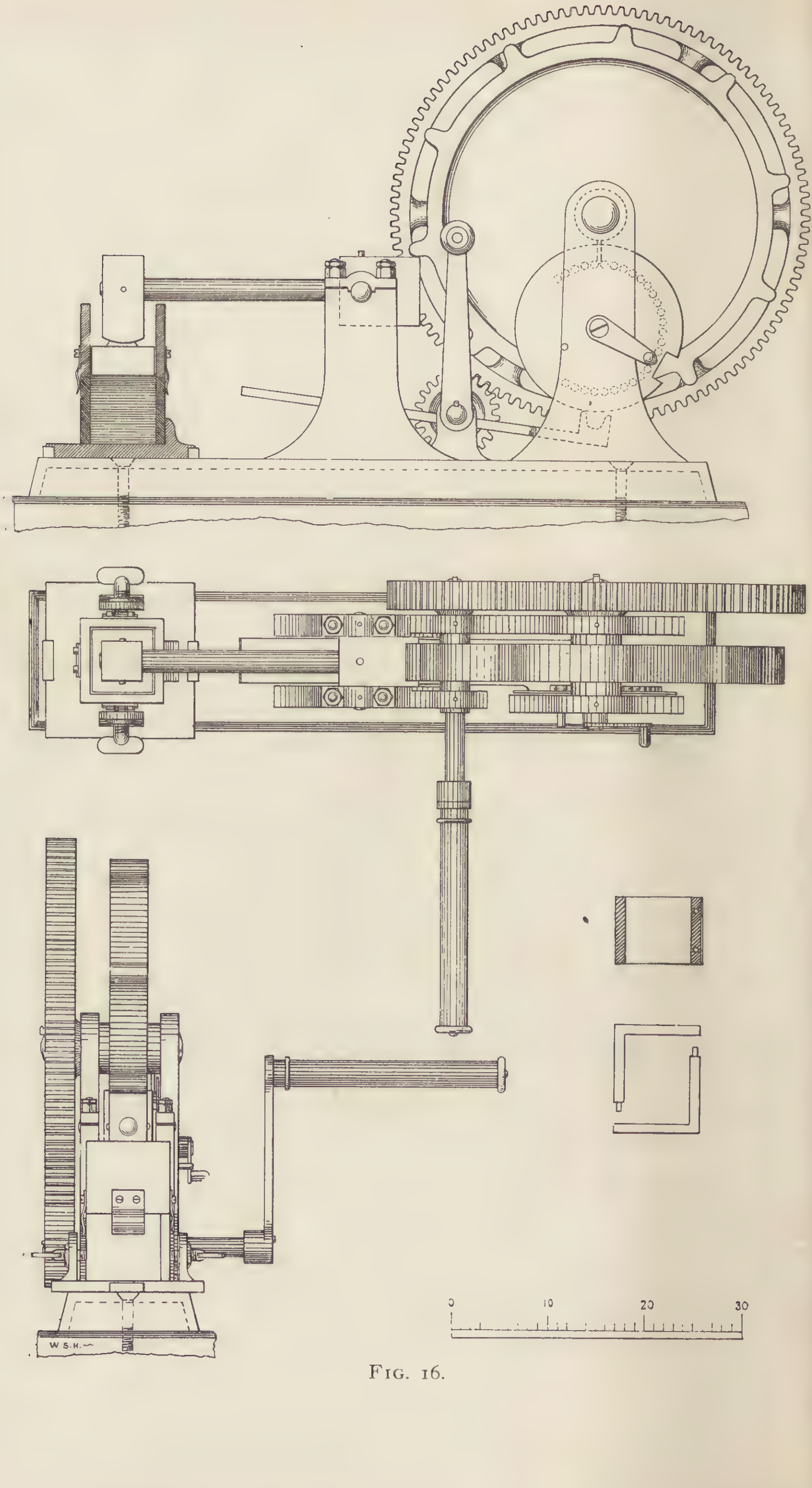

Fig. 16.

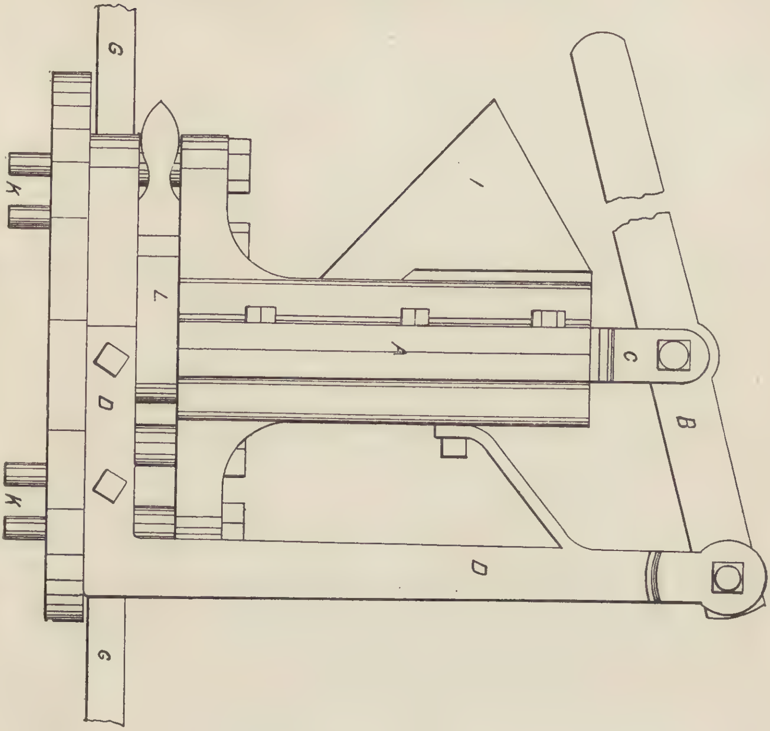

Fig. 17.

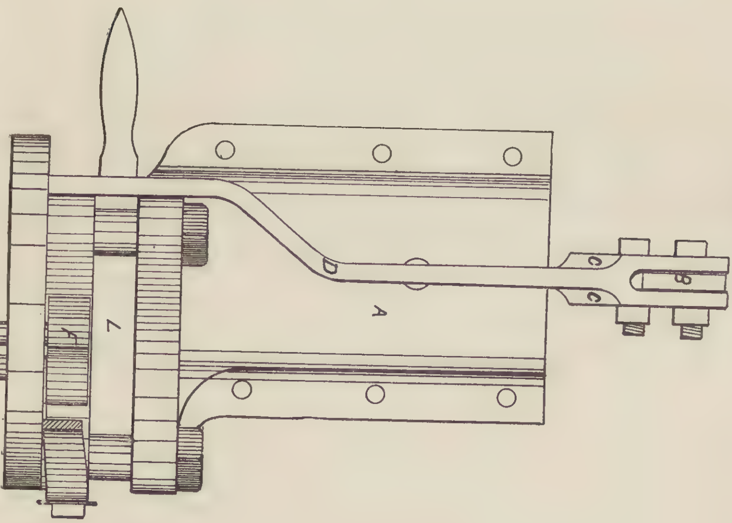

Fig. 18.

"shaped surfaces. The lower case and half the upper one is "filled with the mortar to be tested and a plate laid upon its "surface. On this plate the blows are delivered. It is of "vital importance that the apparatus rest on a firm non-elastic "foundation, preferably it should be placed and fastened on a "pier of masonry."

The Jameson Briquette Machine.—The description of the machine is as follows: The main portion of the machine consists of the cylinder *A*, Figs. 17 and 18, which is flanged at the lower end, this flange corresponding in shape and size to the upper part of the base as seen in Fig. 19. The cylinder

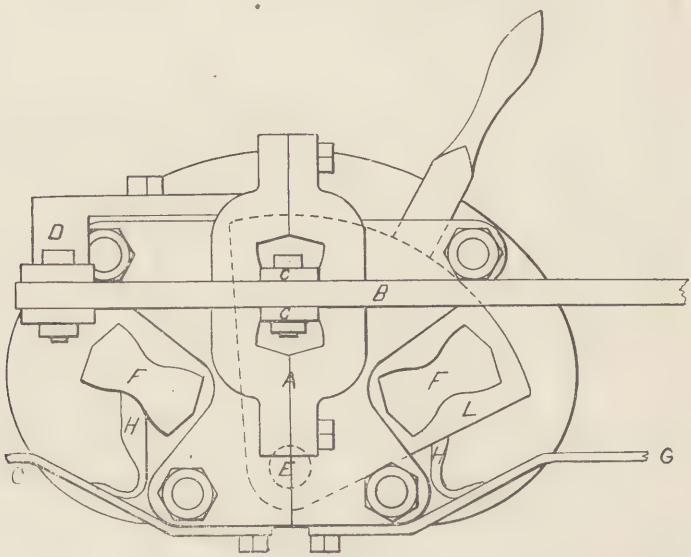

FIG. 19.

is bolted to the base by four bolts, each bolt provided with a filler that holds the lower face of the cylinder 1 inch above the base plate. Both of these faces are accurately planed.

It is between these two planed faces that the molding plate *L*, Fig. 20, swings, the fillers on the bolts acting as stops.

The cylinder *A* is made in two parts, bolted together. The bore is the shape and size of the briquette and is shown in plan in Fig. 19.

In this bore works a solid plunger of the shape of the bore. The length of this plunger is of sufficient length to cover the feed hole, when at its lowest point. The plunger is connected to the lever *B* by the connecting rod *C*. The fulcrum of the lever *B* is at *D*.

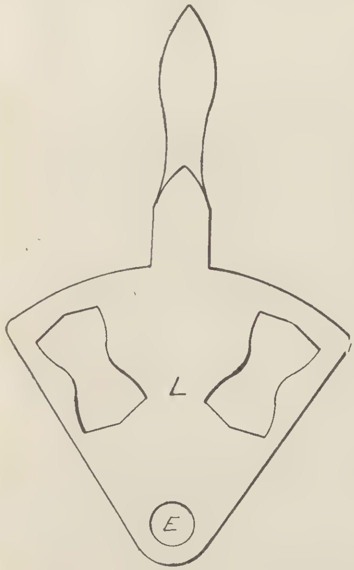

FIG. 20.

About the point *E*, Fig. 19, the plate *L* swings in such a manner, that when at either extreme one of the openings is directly beneath the bore of the cylinder, while the other is directly over the extractor Fig 19.

When the extractor is lowered its top is a little below the lower side of the molding plate. These extractors *F* and *F* are of the shape of the opening in the molding plate, and are raised by the levers *G G*. The object of the extractors is to force the briquettes from the mold. On the outside of the cylinder is the hopper *I*, Fig. 17.

The method of operation is as follows: The piston is raised until it is above the feed hole, and the cement or mortar in the hopper is forced into the cylinder.

The molding plate is pushed against one of the stops so as to bring one of the openings under the cylinder bore.

The lever *B* is forced down, causing the plunger to force the cement or mortar into the opening in the molding plate. The molding plate is then swung against the other stop. This movement cuts off the briquette and places it directly over the extractor. The other opening in the molding plate is directly under the cylinder bore. The extractor is raised by the lever *G*, the briquette forced out and removed. The extractor is lowered, the main plunger forced down again, the molding plate swung and another briquette made. The

cylinder will hold sufficient material for three briquettes. It should then be filled again.

The machine is best operated by two men, one to feed and operate the long lever, and the other to swing the molding plate and remove the briquettes.

In regard to the capacity of the machine: three students have made three thousand briquettes in ten hours.

As this machine was an experiment and the strictest economy as to cost was necessary, it is in some respects crude, and could be made much more convenient for working. Probably the first fault that will be noticed is the fact that there is no method of regulating the amount of pressure used in making the briquette or rather that in no way can one be sure that an equal pressure is exerted on each of the briquettes. Experiments were made to test the necessity of this, and as no decrease in the per centage of variation in the briquettes was found, such an exact regulation was not deemed necessary. This probably arises from the fact that the actual pressure is so great under all circumstances that the actual variation forms but a small per centage of it, not sufficient to vary the results.

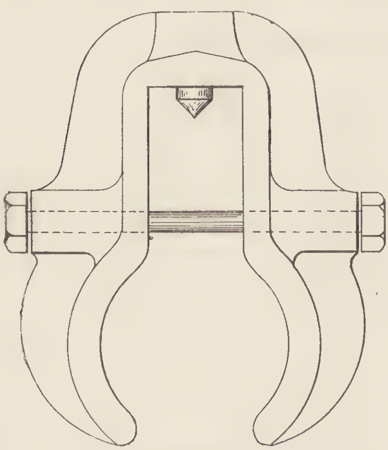

FIG. 21.

In experimenting with a fixed pressure, the plunger was lowered until it rested upon the top of the cement in the cylinder. Then a weight was dropped a fixed distance upon it.

Clips.—The shape of the clips is shown in Figs. 21 and 22. In the early testing of cements the briquette was placed in these clips in direct contact with the metal. In time, however, this was found to be objectionable from the fact that the briquettes were not always of such a form that the clips came to a full bearing. The consequence was that the clips, only

bearing on one side, brought a cross-strain upon the briquette, and it often broke at a point much below the normal strain or else broke at some point other than the minimum section.

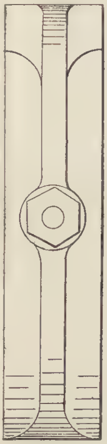
Fig. 22.

This fact led in a short time to the cushioning of the briquette by putting pieces of blotting paper between it and the clips. In this way much of the evil was done away with, but it was more or less a nuisance to use the blotting paper and there was an irregularity of practice among different investigators.

Sheets of rubber were tried with marked success, and this led at once to the making of the clips of the form shown in Fig. 23, where that portion of the *clip* that comes in contact with the briquette is covered with a small piece of rubber tubing. The arrangement is such that this tubing can be replaced when necessary, and much more uniform results have been obtained since the introduction of the rubber buffer.

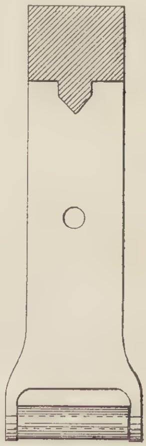
Fig. 23.

In placing briquettes in the testing machine care should be exercised that everything comes to a full and even bearing. Nothing should be hurried, and a certain amount of skill is necessary. The strain should be applied very slowly, about 500 pounds per minute. When the briquette has broken, a note should be made of the number of pounds' strain at which it broke, and remarks as to the character of the fracture,—whether it occurred at the minimum section or not, and whether it is a square, even fracture. If not at the minimum section, or if irregular, in shape, a note should be made of any apparent fault in the briquette that might account for the irregularity of breaking. Even with the greatest possible care being used in the making of the briquettes and in their subsequent manipulation there will be found a great per centage of

variation in the results obtained. An examination of the tests made in the Testing Laboratories of the State University of Iowa will clearly show this.

Taking a good imported Portland cement and making the briquettes by hand, it was found at the end of twenty-eight days that there would be a variation in the breaking strength of about ten per cent. When the briquettes were made in large quantities in Jameson's Briquette Machine the variation was found to be reduced to about four per cent., and upon selecting one hundred apparently perfect briquettes from a lot of five hundred, the per centage of variation fell below two per cent. These experiments also show the great advantage that obtains with machine-made briquettes.

The author has never had the opportunity of using the Böhme Hammer apparatus, and therefore can give no comparative results.

In order to insure a greater uniformity in hand-made briquettes it is the usual custom in England to mold the briquette in the following manner: the description is taken from "A Manual of Lime and Cement," by A. H. Heath:

"The mixed cement is to be lightly placed in the molds, and "then is to be pressed for five minutes under a load of ten "pounds placed on top of the soft cement projecting above "the mold. The loading block to be shaped to the mold, with "$\frac{1}{64}$ inch clearance, and is to be placed on the cement symmetrically; after loading, the surplus cement to be cut off "with a trowel or knife, and the briquette smoothed level "with the top of the mold." But with the exercise of all possible care the hand-made briquettes do not in any way compare with those made by machine. The advantage of the machine is two fold. First the great pressure to which the briquettes are subjected (almost six hundred pounds) makes them of a nearly uniform density, and allows of their being taken at once from the machine and placed on a slab.

Second, in the rapidity with which they can be made. This rapidity is not only an advantage in itself as a saving of time, but has also this great advantage, that it allows of the mixing

of a much greater quantity of mortar at once, and thus making a greater number of briquettes from mortar that is uniform throughout.

In making briquettes by hand it is usual to mix sufficient mortar to make five briquettes. If more mortar than this is made at one time and the cement is in any way quick setting, there is danger of an incipient set and the necessity of reworking the mortar. The evils attending such an operation are pointed out in the chapter upon the using of cement. In making briquettes by machine sufficient mortar for eighty briquettes can be mixed at once, and the time required to make this number by machine is less than that required to make five by hand.

Mixing the Mortar.—Until within a few years the briquettes for testing cement were made solely of neat cement.

The American Society of Civil Engineers, however, in 1885 adopted the suggestion of their committee that in testing cement the briquettes should be made of neat cement. Then, for natural cements, 1 part cement and 1 part sand; and for Portland cements, 1 part cement and 3 parts sand.

The proportions are by weight, and the per centage of water used is in proportion to the combined weight of cement and sand. The actual amount of water used depends to some extent upon the quality of both the sand and cement, and also the proportions in which they are used. As little water as possible should be used, just sufficient to give the mass the consistency of damp sand. There is very little danger of using too little water. An approximate amount is 20 to 25 % for neat cement, 15 % for one part of sand, and 10 to 12 % for three parts of sand. The actual amount used should be carefully noted.

The temperature of both the water and the laboratory should be constant, between 60° and 70° Fah.

The mixing of the mortar for testing should be done upon some non-absorbent surface. If only a few briquettes are to be made, say five or ten, a heavy glass slab answers the purpose. When a larger amount, sufficient for use in a

briquette machine, the author has found a small porcelain-lined sink the most convenient.

The cement and sand are most thoroughly mixed dry, and then the proper amount of water added gradually. The mixing must be most thoroughly done until the whole mass is of a uniform dampness and consistency. This mixing must also be carried on with rapidity.

As soon as the mixing of the entire mass has been completed the work of molding the briquettes should begin at once.

Sand.—There are two kinds of sand that are used in cement tests. Which should be used depends upon the object for which the tests are being made. If this object is to determine the value of the cement for any particular piece of work, the sand used should be the sand that is to be used in the work, and it is the mortar that is to be tested, not the cement alone.

In case, however, the results should be unsatisfactory, and any doubt exist as to the quality of the sand, then the cement should be tested with "standard" sand before being rejected. In laboratory tests where a long series of experiments are being carried on, the results of which are to be compared with those obtained by other experimenters, it is necessary that some standard sand should be used, sand that can be readily duplicated if desired. For this purpose, crushed quartz of a given definite size, such as is used for the making of sand-paper, should be used. This sand can be procured of any desired size, is clean, sharp and in every way most excellent. Its use renders possible the carrying on of comparative tests at any number of places.

Pans or Slabs.—If the briquettes are made by hand in molds, they must be left in the mold sufficiently long to become hard, usually not less than two hours. If machine made, they are delivered direct from the machine, in a condition to be handled. These fresh briquettes should be placed upon some non-absorbent substance. For a small number, sheets of glass are very convenient; for greater numbers,

shallow pans of galvanized iron are good. These pans, slabs, etc., are sold by all dealers in testing laboratory outfits. When the briquettes are placed on these glass slabs or in the pans, they are covered with a damp cloth and allowed to remain there for twenty-four hours.

The temperature of the testing room should not be above 70° nor below 60°, and of course the briquettes should not be left in any position where they will be exposed to the sun or any violent change of temperature. After twenty-four hours under a damp cloth, a portion of the briquettes should be immersed in water.

Tanks.—The galvanized iron pans for sale by the dealers are about two inches deep, and can be had to hold one hundred briquettes, the briquettes being on edge.

Where a briquette machine is used, as in a University Laboratory, and a great number of briquettes made, the author has found the following arrangement of tanks very satisfactory. The tanks are made of wood of any length that will suit the size of the tank room. They are about four inches deep on the inside, and three or four inches wider than the galvanized iron pans. There is an inlet for the water at one end and an overflow at the other. As many of these tanks can be made as is necessary, and they can be placed, the one over the other, with sufficient space between. The pans containing the briquettes can be set in them without in any way disturbing the briquettes, and the water turned on. Each pan is numbered, and thus the different briquettes are entirely distinct.

Increased Temperature.—In mixing the mortar for briquettes careful note must be made as to any increase in temperature. This increase in temperature indicates the presence of free lime. In the best Portland cements the increase of temperature upon the addition of water is very slight, but in some cases is sufficient to be noted by the hand. With the light-burned natural cements there is a very marked rise in the temperature, and in working any such cement in the laboratory, rubber gloves should be used. The amount of the

increase of temperature is, to a certain extent, proportional to the amount of free lime in the cement, and various attempts have been made to use this fact as a test for the actual per centage of free lime present. This method, however, of determining the free lime has not been found practical, owing to the fact that, to make such observations of any value, it is necessary to use more care and refinement in conducting the experiments than is practically possible in a cement laboratory.

Setting.—The test for setting and hardness that is usually used is what is called the needle test. This test was first used, to any extent, in this country by Gen. Q. A. Gilmore, and is thus described in his "Practical Treatise on Limes, Hydraulic Cements and Mortars" pages 30, 31:—"*Their relative hardness*" (referring to the setting of different cements): "This "was measured by the penetration of a steel point or needle, "impelled by the impact of a falling body. The needle, which "is slightly conical, or tapering towards the point, is truncated "at right angles to the axis, so as to give a diameter at the "lower end of $\frac{1}{12}$ of an inch. It protrudes from a socket in "the lower extremity of a vertical rod or spindle to which it is "firmly secured by means of a thumb-screw. To the upper "extremity of the spindle is attached a diagonal scale of steel, "accurately graduated to tenths, hundredths and thousandths "of an inch, and provided with a horizontal index firmly fixed "to the frame-work of the instrument.

"The absolute penetration of the needle is obtained by "taking the difference between the index readings before and "after impact. The falling body is a hollow metal cylinder, "weighing one pound, of which the exterior diameter is about "equal to the length.

"This cylinder, in its descent, passes freely over the spindle, "and strikes upon the shoulder attached just above the screw. "The mortar used to determine the hardness was that of the "broken prisms, and the penetrations were taken the same "day, generally but a few hours after they had been broken. "As these fragments were two inches square in cross-section, "and seldom less than two and one-half inches long, they

"admit of several trials with the needle. An average of not "less than four penetrations, and sometimes more, at each "end of the prisms, was taken on all occasions, except when "the fragment split open at a lower number, which was some- "times the case."

Gen. Gilmore also used a $\frac{1}{12}$ inch wire with flat end, loaded with $\frac{1}{4}$ lb., and a $\frac{1}{24}$ inch wire loaded with one pound. These were used on cakes of neat cements 2 or 3 inches in diameter, $\frac{1}{2}$ inch thick in the center and $\frac{1}{4}$ inch thick at the edges. One cake was left in the air and one cake immersed in water. The time at which the loaded wires cease to penetrate the pat is to be noted.

In England a Portland cement is considered to be quick setting when it will bear the $\frac{1}{12}$ inch needle loaded with 4 ozs. in ten minutes after mixing with water, and to be slow setting if the time occupied is 30 minutes or upwards to 5

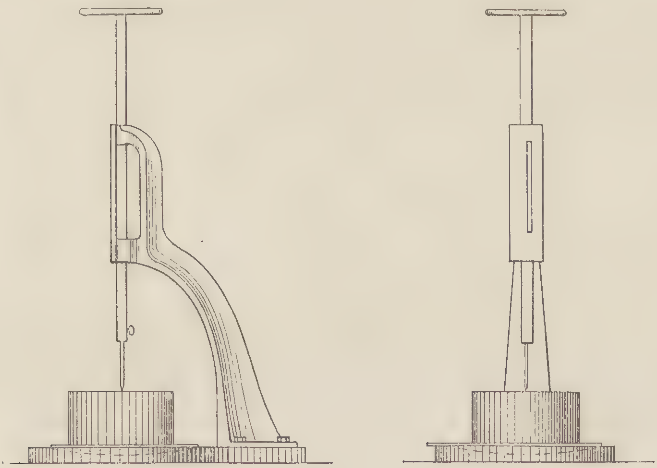

FIG. 24.

hours. When not sufficiently hard to bear the needle after 5 hours, the cement may be rejected. These tests are made with neat cement.

Vicat's needle test, Fig. 24, is used at the Boulogne Harbor Works; 10½ ozs. (300 grammes) upon a needle with a cross-section of 0.00155 square inches (1 square millimeter). At

Boulogne a slow setting cement was specified; and one that would support this needle in less than half an hour was rejected.

German Needle Test.—The standard German needle test is a needle that has 0.0015 square inch sectional area, weighted with 10 ozs. This is placed vertically upon the top of the cement pat to be tested. This pat is $1\frac{1}{2}$ inches thick and may be inclosed in a metal ring or mold 3.15 inch interior diameter.

The cement is said to be completely set when the needle will make no impression upon the top, and setting is said to have begun when the needle fails to pass through the entire cake.

The author has tried these various methods of testing the hardness and the setting properties of cements and has found them all more or less unsatisfactory. In the first place, there is an absence of uniformity of methods used by the different experimenters, and this lack of uniformity renders any comparison of the results obtained of very little value.

Another source of error or lack of uniformity results from the fact that too much depends upon the personal equation of the investigator. No two persons will obtain the same result on the same cement with any of these needle tests.

In order to make the tests of the greatest value they must be made to a great extent mechanically, and the results obtained and recorded automatically. The results obtained by any of the methods heretofore described are only obtained at stated intervals, and are merely isolated results.

There is one point in the setting of cement that is not touched upon in these methods and that is the rate of setting. We get merely two points in a curve,—the beginning and the end. We know when the cement begins to show an appreciable set, and we know the point at which the increase of hardness becomes so slow that the cement is said to be set. Between these two points we have nothing to show the shape of the curve. In any tests that have been made, that show rate of setting from time to time, it will be found that different cements set in an entirely different manner.

The author has used a machine in his own laboratories in the summer of 1894, for the examination of the setting quali-

ties of cements, that has given most satisfactory results, and, so far as he knows, is of original design.

A small drill such as is used by dentists, with a bur on the end $\frac{1}{8}$ of an inch in diameter, takes the place of the needle. The shank of this drill is about $1\frac{1}{2}$ inches long and smaller than the burr.

The drill is clamped to a vertical spindle. This spindle has a screw thread cut on it and passes through a metal plate, where it fits into a corresponding thread. This plate is fixed in a horizontal position and the spindle is raised or lowered when turned in the plate.

The spindle is connected with clock-work in such a manner that a *slow* rotary motion can be given to it. This clock-work is driven by a light spring and the spindle, gearing, etc., must be kept clean and well oiled in order to insure uniformity of work.

The upper end of the spindle passes above the clock-work, to a bell crank the shorter arm of which is fastened to the spindle. The longer arm carries a pencil that records any movement on a chronograph, the chronograph being operated by separate clock-work.

The method of using the machine is as follows: a pat of neat cement in a mold is placed in the machine below the drill. The drill is lowered until it just touches the cement, then the clock-work of the machine and of the chronograph are both started.

The drill rotates and works its way down into the cement, the distance that it penetrates being recorded on the chronograph, with the time. As the cement begins to set, the amount of resistance encountered by the drill becomes greater, the rate of rotation less, and consequently the rate of penetration less, until at last a point is reached when the cement has became so hard that the drill can make no impression upon it and the machine stops. We then have written upon the chronograph an exact autobiography of the rate and manner of setting of the cement. Nothing has been left to the skill or lack of skill in the investigator and the results are continuously recorded.

Adhesion.—The best comparative results in the tests for adhesion can be obtained by using two pieces of coarsely ground glass about 4 inches wide, 8 inches long and 1 or $1\frac{1}{2}$ inches thick. If this is used in a number of experiments, carried on at different times and in different places it insures a uniformity of material upon which to work.

The mortar should be made in the required proportions, using less water than would be used in ordinary masonry work.

The mortar is then spread upon one piece of glass and the other piece placed at right angles with the first as shown in Fig. 25 and pressed down until the mortar joint is $\frac{1}{4}$ of an inch thick.

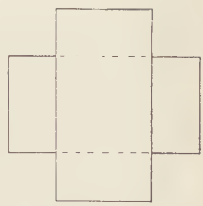

FIG. 25.

The sample is then allowed to stand 24 hours in the air under a damp cloth and then immersed in water. They are pulled apart at the end of 7 or 28 days.

When it is wished to make the tests for any particular piece of work and the results are not to be compared with results obtained in other places. The material (brick or stone) that is to be used in the work should be used in the tests. When brick or stone are used in tests they should be wet in exactly the same manner as they are to be in the work.

A few tests made in this way will not only give the adhesive value of the mortar, but by varying the treatment of the brick or stone used, very interesting results can be obtained in regard to the value of thoroughly wetting the material before the mortar is applied.

Cross-Strain.—The specimen to be subjected to cross-strain can be of almost any size. About two inches square and eight inches long is convenient. The making of the specimen and its subsequent treatment are governed by the rules that have been given for the making of briquettes. When the specimen is to be broken it should rest upon two supports a known distance apart. With an eight inch specimen these supports are usually six inches apart.

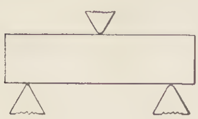

FIG. 26.

The form of the support should be similar to that shown in Fig. 26. The knife edge is slightly rounded so as not to cut into the specimen. The load is brought to bear upon the specimen midway between the supports.

Blowing.—There is one most important feature that all commercially good cements must have, and that is stability of form. It is absolutely necessary for the future durability of the work that the cement used should neither shrink nor swell after the process of setting has once commenced.

It is one of the peculiarities of Portland cement that when its constituents have been improperly mixed or the process of manufacture improperly carried on, it will have a tendency to expand, crack and disintegrate after the setting has commenced. This expanding, cracking and disintegrating is called "blowing," and such cement is said to be "blowey" cement. There are a number of methods used in testing for this feature. Some of the cement is mixed with a small amount of water and then pressed firmly into a straight glass lamp chimney. If any dangerous amount of expansion takes place the chimney will be broken. By this method also can be examined any shrinkage of the cement. This is done by pouring some colored liquid into the chimney after the cement has thoroughly set, and an idea of the amount of shrinkage can be obtained by the amount of liquid that runs down the inside. In Germany at some of the cement works great care has been taken to investigate with accuracy the actual amount of expansion that takes place. For this purpose Bauschinger's caliper apparatus has been used. With this apparatus the expansion can be measured with an accuracy of $\frac{1}{5000}$ of an inch.

This expansion may not be perceptible until two or three days after the setting has begun, or it may become perceptible almost immediately. The quicker setting the cement is, the more quickly the blowing will commence.

One of the best methods of testing for blowing is as follows: viz.: Gauge the cement with only sufficient water to give it the consistency of damp sand; make a few ounces of it into a pat about 3 inches in diameter, $\frac{1}{4}$ or $\frac{1}{8}$ inch thick at the

edges and $\frac{1}{2}$ inch in the center. Make this pat upon a plate of glass or some non-absorbent material. The pat should be left on the glass under a damp cloth for 24 hours, and then immersed in water. If the pat, at the end of three days in water, shows no signs of cracking or disintegrating at the edges, it can be considered safe. In examining the pat for cracks the fine hair-like cracks found on the surface, that cross and recross each other are not due to blowing, but are merely the result of slight changes in temperature. They do not denote a poor cement. The cracks due to blowing are wedge-shaped, radiating from the center, and usually accompanied by a certain amount of disintegration.

In order to hasten this test, and thereby save much time, the following method is used and recommended by Mr. Henry Faija, M. Inst. C. E. The apparatus consists of a vessel of such design that water in it can be maintained at a constant temperature of 110° to 115° Fah.

The vessel is covered and under the cover but above the water level is a rack upon which the pat can be placed. The pat is made and placed on the rack where it is subjected to the moist atmosphere above the warm water, the temperature of the moist air being a little over 100° Fah. The pat is kept on the rack about 6 or 8 hours and then immersed in the warm water for 16 or 18 hours. If at the end of that time it remains firm, showing no signs of disintegration and still adheres to the glass, it can be considered safe.

In case however, that it does disintegrate, it does not necessarily indicate that either the constituents or method of making are at fault. The cement may simply be too fresh. Cement when tested about twenty-four hours after being ground will often "blow" but if well stored will in a short time become good cement. When the cement being tested is fresh and "blows" there is the possibility that it may be good cement and in order not to unjustly condemn it, a sufficient quantity should be spread out in a thin layer and then tested again at the end of three or four days.

Another peculiarity of some Portland cement is that when

taken from the mill and gauged with water it will be found to be moderately slow setting. Gauge the same cement in 24 or 30 hours and it will set almost before it can be mixed. Store in a cool dry place and in a few days it will become more slow setting.

The older Portland cement is the more slow setting it is, and usually the greater the ultimate strength reached by the mortar. This of course is only true when the cement has been stored in a dry, cool place.

In regard to slow setting cement. Tradition attributes the property of slow setting to the presence of an excessive amount of lime. This is partly true. That is a cement that has an excessive amount of lime in it, is usually slow setting, but not invariably so. There are however, other factors that affect the setting of cement even more than the presence of an excessive amount of lime.

Take a cement made with the correct proportions of lime, silica, alumina and iron, and this cement may be either slow or rapid setting, depending, first, upon its age as before noted and, second, upon the degree of calcination to which it has been subjected.

An under-burned cement will set quicker than an over-burned one. This is true until a point of absolute vitrifaction is reached, when the resulting product will never set.

Abrasion.—There is one more test to which cement is sometimes subjected, and that is abrasion. Cement that is to be used for sidewalks, floors and artificial stone paving blocks should be subjected to this test. Not only should the neat cement be tested but also the mixture of cement and sand that is to be used in the actual work.

The resistance of a cement walk to wear depends not only upon the character of the cement used but also the hardness and toughness of the aggregate.

First the aggregate and then cement, or vice versa, is worn away, and if the cement is not hard but still has sufficient cementing qualities to hold the aggregate in place, the walk may still be durable.

The method of making the test for abrasion is the same as that employed with paving bricks, etc. A cube of the neat cement or cement and sand is made. This is allowed to harden under water for not less than seven days. The cube is then taken from the water and thoroughly dried. After drying, it is brushed off with a stiff brush and carefully weighed.

The grinding machines are of two kinds. The first, which has been much used in Berlin: a horizontal cast-iron disc that rotates about 22 rotations per minute. The cube, 1 cm. in size, is held in a clamp and pressed down by a simple lever, weighted with 56 lbs.; 308 grains Napus Quartz No. 3 is put on the plate at the start and the same amount at the end of the fifteenth revolution. After 30 revolutions, the cube is taken out and weighed again, and the percentage of loss noted.

The author has found the following apparatus most satisfactory. The cube used was 3 inches; a coarse emery wheel 4 inches wide and 15 inches in diameter. The wheel was set vertically and given 100 revolutions per minute. The cube was loaded by a weight of 10 lbs. at the end of lever 3 feet long. The cube was subjected to 200 revolutions.

In concluding these remarks upon the testing of Portland cement we wish to say that nothing has done more to improve the quality of Portland cement than a rigid system of tests, and an absolute enforcement of the specifications in regard to tests.

Cement makers and users soon discovered what degree of excellency was possible, with given raw materials. They also soon discovered what were the causes that resulted in an inferior cement.

When all of this became known, there was no further excuse for putting poor cement upon the market. Much poor Portland cement was still, however, sold and there existed much irregularity in the quality of the output, at different times, from the same works. All of this was merely the result of carelessness on the part of the cement makers and this carelessness continued because the users of cements were either ignorant of what they should have received for their

money, or because they did not hold the makers down to strict tests and specifications.

The marked improvement in the output of cement manufactories began about 1863 or '65, and in Germany. England had been the home of Portland cement since its invention and commanded the markets of the world. In order to open up a place for German cement it was necessary to make some improvement in the product. This was not an affair of much difficulty as the English makers had grown careless. This superiority of production, however, was not in itself sufficient.

The German makers must not only make a Portland cement better than the English article, but they must make the users of cement appreciate the fact that their cement was the best.

They accomplished this by simply guaranteeing their cement. That is, they guaranteed that their cement should give not less than certain specified results in certain tests. The two tests were fineness and tensile strength. The test for fineness was a residue of not less than 3 % on a 2,500-mesh sieve, and in tensile strength of not less than 500 lbs. per square inch at the end of 7 days. The briquette being of neat cement.

This guaranty was entirely optional on the part of the makers, and was done as an advertisement.

From year to year, however, the effect has been to improve the quality of the cement.

In order to advance with as much rapidity as possible along the lines of improvement, the Association of German Cement Manufacturers was founded in 1877. They have set forth a set of specifications for the uniform Delivery and Testing of Portland Cement, and these specifications are now generally accepted.

They have also defined what material shall be sold under the name of Portland cement, and any member who mixes any foreign material with the raw material before burning, or during burning, or with the cement after burning, and sells the same under the name of Portland cement shall be expelled from the Association. The result, of the work of this Associ-

ation, has been that to-day the factories which belong to it turn out cements that never fall below a certain standard, and this standard is sufficiently high to make any of the cement safe for all ordinary uses. It is this uniformity of product, not only in the product of one factory at different times, but in the product of a number of factories at all times, that places the German Portland cements far in advance of any others.

CHAPTER V.

ABSTRACTS FROM AMERICAN, GERMAN, FRENCH, AND AUSTRIAN SPECIFICATIONS FOR PORTLAND CEMENT.

American Society of Civil Engineers—Report of the Committee on a Uniform System for Tests of Cement.

TESTS OF CEMENT.

The testing of cement is not so simple a process as it is sometimes thought to be. No small degree of experience is necessary before one can manipulate the materials so as to obtain even approximately accurate results.

The first tests of inexperienced, though intelligent and careful, persons, are usually very contradictory and inaccurate, and no amount of experience can eliminate the variations introduced by the personal equations of the most conscientious observers. Many things, apparently of minor importance, exert such a marked influence upon the results, that it is only by the greatest care in every particular, aided by experience and intelligence, that trustworthy tests can be made.

The test for tensile strength on a sectional area of one square inch is recommended, because, all things considered, it seems best for general use. For the small briquette there is less danger of air bubbles, the amount of material to be handled is smaller, and the machine for breaking may be lighter and less costly.

The tensile test, if properly made, is a good, though not a perfect, indication of the value of a cement. The time requisite for making this test, whether applied to either the natural or the Portland cements, is considerable (at least seven days, if a reasonably reliable indication is to be obtained), and as work is usually carried on is frequently impracticable. For this reason, short time tests are allowable in cases of necessity though the most that can be done in such testing is to determine if the brand of cement is of its average quality. It is believed, however, that if a neat cement stands the one day tensile test, and the tests for checking and for fineness, its safety for use will be sufficiently indicated in the case of a brand of good reputation: for, it being proved to be of average quality, it is fair to suppose that its subsequent condition will be what former experiments, to which it owes its reputation, indicate that it should be. It cannot be said that a new and untried cement will by the same tests be proved to be satisfactory; only a series of tests for a considerable period, and with a full dose of sand, will show the full value of any cement; and it would be safer to use a trustworthy brand without applying any tests whatever than to accept a new article which had been tested only as neat cement and for but one day only.

The test for compressive strength is a very valuable one in point of fact, but the appliances for crushing are usually somewhat cumbersome and expensive, so much so that it seems undesirable that both tests should be embodied in a uniform method proposed for general adoption. Where great interests are at stake, however, and large contracts for cement depend on the decision of an engineer as to quality, both tests should be used if the requisite appliances for making them are within reach. After the tensile strength has been obtained, the ends of the broken briquettes, reduced to one-inch cubes by grinding and rubbing, should be used to obtain the compressive strength.

The adhesive test being in a large measure variable and uncertain, and therefore untrustworthy, is not recommended.

FINENESS.

The strength of a cement depends greatly upon the fineness to which it is ground, especially when mixed with a large dose of sand. It is, therefore, recommended that the tests be made with cement that has passed through a No. 100 sieve (10,000 meshes to the square inch) made of No. 40 wire, Stub's Wire Gauge. The results thus obtained will indicate the grade which the cement can attain, under the condition that it is finely ground, but it does not show whether or not a given cement offered for sale shall be accepted and used. The determination of this question requires that the tests should also be applied to the cement as found in the market. Its quality may be so high that it will stand the tests even if very coarse and granular, and on the other hand, it may be so low that no amount of pulverization can redeem it. In other words, fineness is no sure indication of the value of a cement, although all cements are improved by fine grinding. Cement of the better grades is now usually ground so fine that only from 5 to 10 % is rejected by a sieve of 2,500 meshes per square inch, and it has been made so fine that only from 3 to 10 % is rejected by a sieve of 32,000 meshes per square inch. The finer the cement, if otherwise good, the larger dose of sand it will take, and the greater its value.

CHECKING OR CRACKING.

The test for checking or cracking is an important one, and though simple should never be omitted. It is as follows: make two cakes of neat cement, 2 or 3 inches in diameter, about $\frac{1}{2}$ inch thick, with thin edges. Note the time in minutes that these cakes, when mixed with water to the consistency of a stiff plastic mortar, take to set hard enough to stand the wire test recommended by Gen. Gilmore, $\frac{1}{12}$-inch diameter wire loaded with $\frac{1}{4}$ of a pound, and $\frac{1}{24}$-inch loaded with 1 pound. One of these cakes, when hard enough, should be put in water and examined from day to day to see if it becomes contorted, or if cracks show themselves at the edges, such contortions or cracks indicating that the cement is unfit

for use at that time. In some cases the tendency to crack, if caused by the presence of too much unslaked lime, will disappear with age. The remaining cake should be kept in the air and its color observed, which, for a good cement, should be uniform; the Portland cements being of a bluish-gray throughout, yellowish blotches indicating a poor quality; and the natural cements being light or dark, according to the character of the rock of which they are made. The color of the cements when left in the air indicates the quality much better than when they are put in water.

TESTS RECOMMENDED.

It is recommended that tests for hydraulic cement be confined to methods for determining fineness, liability to checking or cracking, and tensile strength; and for the latter, for tests of seven days and upward, that a mixture of one part of cement to one part of sand for natural cements, and three parts of sand for Portland cements, be used, in addition to trials of the neat cement. The quantities used in the mixture should be determined by weight.

The tests should be applied to the cements as offered for sale. If satisfactory results are obtained with a full dose of sand, the trials need go no further. If not, the coarser particles should first be excluded by using a No. 100 sieve, in order to determine approximately the grade the cement would take if ground fine; for fineness is always attainable, while inherent merit may not be.

NOTE.—Your committee thinks it useful to insert here a table showing the average minimum and maximum tensile strength per square inch which some good cements have attained when tested under the conditions specified elsewhere in this report. Within the limits given in the following table, the value of a cement varies closely with the tensile strength when tested with the full dose of sand:

American Natural Cement, neat:

One day; one hour, or until set, in air, the rest of the 24 hours in water, from 40 pounds to 80 pounds.

One week; one day in air, 6 days in water, from 60 pounds to 100 pounds.

One month (28 days); one day in air, 27 days in water, from 100 pounds to 150 pounds.

One year; one day in air, the remainder in water, from 300 pounds to 400 pounds.

American and Foreign Portland Cements, neat:

One day; one hour, or until set, in air, the rest of the 24 hours in water, from 100 pounds to 140 pounds.

One week; one day in air, 6 days in water, from 250 pounds to 550 pounds.

One month (28 days); one day in air, 27 days in water, from 350 pounds to 700 pounds.

One year; one day in air, the remainder in water, from 450 pounds to 800 pounds.

American Natural Cements, one part of Cement to one part of Sand:

One week; one day in air, 6 days in water, from 30 pounds to 50 pounds.

One month (28 days); one day in air, 27 days in water, from 50 pounds to 80 pounds.

One year; one day in air, the remainder in water, from 200 pounds to 300 pounds.

American and Foreign Portland Cements, one part of Cement to three parts of Sand:

One week; one day in air, 6 days in water, from 80 pounds to 125 pounds.

One month (28 days); one day in air, 27 days in water, from 100 pounds to 200 pounds.

One year; one day in air, the remainder in water, from 200 pounds to 350 pounds.

Standards of minimum fineness and tensile strength for Portland cement, as given below, have been adopted in some foreign countries.

In Germany, by Berlin Society of Architects, Society of Manufacturers of Bricks, Lime, and Cement, Society of Contractors, and Society of German Cement Makers:

Standard of 1877.—Fineness, not more than 25 % to be left on sieve of 5,806 meshes per square inch.

Tensile strength, 1 part cement, 3 parts sand, 1 day in air, 27 days in water, 113.78 pounds per square inch.

Standard of 1878.—Fineness, not more than 20 % to be left on the sieve, as above.

Tensile strength, same mixture and time as above, 142.23 pounds per square inch.

In Austria, by Austrian Association of Engineers and Architects:

Standard of 1878.—Fineness same as German of 1878.

Tensile strength, same mixture as above, 7 days, 1 day in air, 6 days in water, 113.78 pounds per square inch.

Twenty-eight days, 1 day in air, 27 days in water, 170.68 pounds per square inch.

In Austria a standard for the minimum fineness and tensile strength of Roman cement was established and generally accepted, as follows:

Standard of 1878.—Fineness, same as Portland.

Tensile strength (1 part of cement, 3 parts of sand) for—

Quick setting (taking 15 minutes or less to set):

Seven days, 1 day in air, 6 days in water, 23 pounds per square inch.

Twenty-eight days, 1 day in air, 27 days in water, 56.9 pounds per square inch.

Slow setting cement (taking more than 15 minutes to set):

Seven days, one day in air, 6 days in water, 42.6 pounds per square inch.

Twenty-eight days, one day in air, 27 days in water, 85.3 pounds per square inch.

The Roman cements correspond to those classified in this report under the head of Natural Cements.

Standards have been adopted also in Sweden and Russia.

MIXING, ETC.

The proportions of cement, sand, and water should be carefully determined by weight, the sand and cement mixed dry, and all the water added at once. The mixing must be rapid and thorough, and the mortar, which should be stiff and plastic, should be firmly pressed with a trowel, without ramming, and struck off level; the molds in each instance, while being charged and manipulated, to be laid directly on glass, slate, or some other non-absorbent material. The molding must be completed before incipient setting begins. As soon as the briquettes are hard enough to bear it, they should be taken from the molds and kept covered with a damp cloth until they are immersed. For the sake of uniformity, the briquettes, both of neat cement and those containing sand, should be immersed in water at the end of twenty-four hours, except in the case of one day tests.

Ordinary, fresh, clean water, having a temperature between 60° and 70° Fah. should be used for water of mixture and immersion of samples.

The proportion of water required varies with the fineness, age, or other conditions of the cement, and the temperature of the air, but is approximately as follows: for briquettes of neat cement, Portland, about 25 %; natural, about 30 %. For briquettes of one part cement, one part sand, about 15 % of total weight of sand and cement. For briquettes of one part cement, three parts sand, about 12 % of total weight of sand and cement. The object is to produce the plasticity of rather stiff plasterer's mortar.

An average of five briquettes may be made for each test, only those breaking at the smallest section to be taken. The briquettes should always be put in the testing machine and broken immediately after being taken out of the water, and the temperature of the briquettes and of the testing room should be constant between 60° and 70° Fah.

The stress should be applied to each briquette at a uniform rate of about 400 pounds per minute, starting each time at 0. With a weak mixture one-half the speed is recommended.

WEIGHT.

The relation of the weight of cement to its tensile strength is an uncertain one. In practical work, if used alone, it is of little value as a test, while in connection with the other tests recommended it is unnecessary, except when the relative bulk of equal weights of cements is desired.

We recommend that the cubic foot be substituted for the bushel as the standard unit, whenever it is thought best to use this test.

SETTING.

The rapidity with which a cement sets or loses its plasticity furnishes no indication of its ultimate strength. It simply shows its initial hydraulic activity.

For purposes of nomenclature, the various cements may be divided arbitrarily into two classes, namely; quick setting, or those that set in less than $\frac{1}{2}$ an hour; and slow setting, or those requiring $\frac{1}{2}$ an hour or more to set. The cement must be adapted to the work required, as no one cement is equally good for all purposes. For submarine work a quick setting cement is often imperatively demanded, and no other will answer, while for work above the water-line less hydraulic activity will usually be preferred. Each individual case demands special treatment. The slow setting natural cements should not become warm while setting, but the quick setting one may, to a moderate extent, within the degree producing cracks. Cracks in Portland cement indicate too much carbonate of lime, and in the Vicat cements too much lime in the original mixture.

SAMPLING.

There is no uniformity of practice among engineers as to the sampling of the cement to be tested, some testing every tenth barrel, others every fifth, and others still every barrel delivered. Usually, where cement has a good reputation, and

is used in large masses, such as concrete in heavy foundations, or in the backing or hearting of thick walls, the testing of every fifth barrel seems to be sufficient; but in very important work, where the strength of each barrel may in a great measure determine the strength of that portion of the work where it is used, or in the thin walls of sewers, etc., etc., every barrel should be tested, one briquette being made from it.

In selecting cement for experimental purposes, take the samples from the interior of the original packages, at sufficient depth to insure a fair exponent of the quality, and store the same in tightly closed receptacles impervious to light or dampness until required for manipulation, when each sample of cement should be so thoroughly mixed, by sifting or otherwise, that it shall be uniform in character throughout its mass.

SIEVES.

For ascertaining the fineness of cement, it will be convenient to use three sieves, viz.:

No. 50 (2,500 meshes to the square inch), wire to be of No. 35 Stub's Wire Gauge.

No. 74 (5,476 meshes to the square inch), wire to be of No. 37 Stub's Wire Gauge.

No. 100 (10,000 meshes to the square inch), wire to be of No. 40 Stub's Wire Gauge.

The object is to determine by weight the percentage of each sample that is rejected by these sieves, with a view not only of furnishing the means of comparison between tests made of different cements by different observers, but indicating to the manufacturer the capacity of his cement for improvement in a direction always and easily within his reach. As already suggested in another connection, the tests for tensile strength should be applied to the cement as offered in the market, as well as to that portion of it which passess the No. 100 sieve.

For sand, two sieves are recommended, viz.:

No. 20 (400 meshes to the square inch), wire to be of No. 28 Stub's Wire Gauge.

No. 30 (900 meshes to the square inch), wire to be of No. 31 Stub's Wire Gauge.

These sieves can be furnished in sets, as follows, an arrangement having been made with a manufacturer of such articles, by which he agrees to furnish them of the best quality of brass wire cloth, set in metal frames, the cloth to be as true to count as it is possible to make it, and the wire to be of the required gauge. Each set will be enclosed in a box, the sieves being nested.

Set A, three cement sieves, to cost $4.80:

No. 100,	. . .	7 in. diameter.
No. 74,	. . .	$6\frac{1}{2}$ " "
No. 50,	. . .	6 " "

Set B, two sand sieves, to cost $4.00:

No. 30,	. . .	8 in. diameter.
No. 20,	. . .	$7\frac{1}{2}$ " "

STANDARD SAND.

The question of a standard sand seems one of great importance, for it has been found that sands looking alike and sifted through the same sieves give results varying within rather wide limits.

The material that seems likely to give the best results is the crushed quartz used in the manufacture of sand paper. It is a commercial product, made in large quantities and of standard grades, and can be furnished of a fairly uniform quality. It is clean and sharp, and although the present price is somewhat excessive (3 cents per pound), it is believed that it can be furnished in quantity for about $5.00 per barrel of 300 pounds. As it would be used for tests only, for purposes of comparison with the local sands, and with tests of different cements, not much of it would be required. The price of the German standard sand is about $1.25 per 112 pounds, but the article being washed river sand is probably inferior to crushed quartz. Crushed granite can be furnished at a somewhat less rate than quartz, and crushed trap for about the same as granite, but no satisfactory estimate has been obtained for

either of these. The use of crushed quartz is recommended by your committee, the degree of fineness to be such that it will all pass a No. 20 sieve and be caught on a No. 30 sieve. Of the regular grade, from 15 to 37 % of crushed quartz No. 3 passes a No. 30 sieve, and none of it passes a No. 50 sieve. As at present furnished, it would need resifting to bring it to the standard size; but if there were sufficient demand to warrant it, it could undoubtedly be furnished of the size of grain required at little, if any, extra expense.

A bed of uniform, clean sand of the proper size of grain has not been found, and it is believed that to wash, dry, and sift any of the available sands, would so greatly increase its cost that the product would not be much cheaper than the crushed quartz, and would be much inferior to it in sharpness and uniform hardness of particles.

MOLDS.

The molds furnished are usually of iron or brass, the price of the former being $2, and of the latter $3 each. Wooden molds, if well oiled to prevent their absorbing water, answer a good purpose for temporary use, but speedily become unfit for accurate work. A cheap, durable, accurate, and non-corrodible mold is much to be desired.

CLIPS.

For using the clips recommended in the preliminary report it was found in some instances that the specimens were broken at one of the points where they were held. This was undoubtedly caused by the insufficient surface of the clip, which, forming a blunt point, forced out the material. Where the specimens were sufficiently soft to allow this point to be imbedded, they broke at the smallest section, but when hard enough to resist such imbedding, they showed a wedge-shaped fracture at the clips. To remedy this, the point should be slightly flattened so as to allow of more metal surface in contact with the briquette. Clips made in this way have been used, and good results obtained.

To adapt the one-inch clips of the Riehle machine, only a

slight amount of work is necessary; the ends being rounded, will admit the proposed new form of briquette, and yet not prevent the use of the old one, thus allowing comparative tests of the two forms to be made without changing the clips.

There should be a strengthening rib upon the outside of the clips to prevent them from bending or breaking when the specimens are very strong.

The clips should be hung on pivots so as to avoid as much as possible cross strain upon the briquettes.

MACHINES.

No special machine has been recommended, as those in common use are of good form for accurate work, if properly used, though in some cases they are needlessly strong and expensive. Machines with spring balances are to be avoided as more liable to error than others.

It is by no means certain that there exists any great difference in well made machines of the standard forms given.

AMOUNT OF MATERIAL.

The amount of material needed for making five briquettes of the standard size recommended is: for the neat cements, about one and two-thirds pounds; and for those with sand, in the proportion of three parts of sand to one of cement, about one and one-quarter pounds of sand and six and two-thirds ounces of cement.

German Specifications for Standard Portland Cement Tests.

Definition. Portland cement is a product resulting from the vitrifaction of a thorough mixture of material, whose principal component parts are lime and alumina, and the grinding of the vitrified material to a fine powder.

1. Packing and Weight: As a rule Portland cement is to be packed in standard barrels of 180 kilo. (397 lbs.), gross weight, and about 170 kilo. (374 lbs.), net weight, and in half standard barrels of 90 kilo. (198 lbs.), gross weight, and about 83 kilo. (133 lbs.), net weight. The gross weight is

to be marked on the barrels. If the cement is called for in bags or barrels of other weight, the gross weight of the same must be clearly marked upon these packages. Losses and variations in weight of the single packages up to 2 % of the same will be allowed. Barrels and sacks, in addition to the weight shall show in legible writing the name and trade mark of the manufacturer.

2. Time of Setting: Slow or quick setting cement may be called for according to the use for which the cement is to be put. Cements which do not set in less than 2 hours, are to be considered slow setting cements.

3. Constancy of Volume: Portland cement shall be of constant volume. As a preliminary test, admitting of forming a rapid opinion, the heating test is recommended. The decisive test shall be that a paste of neat cement made on a glass plate protected against drying and placed under water after 24 hours, shall not show after the lapse of a longer period of time any blowing cracks, or change of shape.

4. Fineness of Grinding: Portland cement shall be so finely ground that a batch of the same shall not leave a residue of more than 10 % upon a sieve of 900 meshes per square centimeter (5,806 meshes per sq. in.). The thickness of the wire of the sieve shall equal half the space between the wires. For test 100 g. ($3\frac{1}{2}$ oz.) of cement shall be used.

5. Tests of Strength: The cohesive power of Portland cement shall be determined by the testing of a mixture of cement and sand. The tests shall be both tensile and compressive, made according to a uniform method, with test pieces of the same form and cross section, and with the same apparatus. At the same time a determination of the strength of the neat cement is to be recommended.

6. Tensile and Compressive Strength: Good slow setting cement, in the proportion of three parts by weight of standard sand to one part of cement shall have when tested, after 28 days' hardening (1 in air and 27 in water), a minimum tensile strength of at least 16 kilo. q. c. m. (16 kilogrammes per sq. centimeter) (227 lbs. per sq. in.). The compressive strength shall be at least 160 kilo. q. c. m. (2,270 lbs. per sq. in.).

Cement which shows a higher tensile or compressive strength admits in many cases of a greater addition of sand, and from this point of view, as well as on account of its greater strength for the same amount of sand, is entitled to a correspondingly higher price.

For slow setting cements the strength after 20 days is less in general than the one above specified, therefore, in giving the results of tests, the time of setting shall also be given.

The tests shall be made in the following manner:

To determine the time of setting cement, a slow setting neat cement shall be mixed 3 minutes, and a quick setting neat cement 1 minute with water to a stiff paste. A cake about 1.5 c. m. (0.59 in.) thick, with thin edges, shall be formed of this paste on a plate of glass. The consistency of the cement paste for this cake shall be such, that when brought with a trowel on the plate, the paste will only begin to run toward the edges of the same after the paste has been repeatedly jarred. As a rule 27 % to 30 % water will suffice to give the necessary consistency to the paste. As soon as the cake is sufficiently hardened, so that it will resist a slight pressure of the finger nail, the cement is to be considered as having set.

For the exact determination of the time of setting, and for determining the beginning of the time of setting, which latter is of importance in the case of quick setting cements, since they must be worked up before they begin to set, a standard needle 300 g. (10 oz.) in weight, and 1 sq. mm. (.00155 sq. in.) in cross section, is used. A metal ring 4 cm. (1.575 in.) in height and 8 cm. (3.15 in.) clear diameter (inside diameter) is placed on a glass plate, filled with cement paste of the above consistency and brought under the needle. The moment at which the needle is no longer capable of completely penetrating the cement cakes is considered the beginning of the time of setting. The time elapsing between this and the moment when the standard needle no longer leaves an appreciable impression on the hardened cake is considered the time of setting.

For making the heat test (3) a stiff paste of neat cement and water is made, and from this cakes 8 cm. (3.15 in.) to 10 cm. (3.94 in.) in diameter and 1 cm. (.394 in.) thick are formed on a smooth, impermeable plate, covered with blotting paper. Two of these cakes, which are to be protected against drying, in order to prevent drying cracks, are placed, after the lapse of twenty-four hours, or at least only after they have set, with their smooth surfaces on a metal plate and exposed, for at least one hour, to a temperature of from 110° C. to 120° C. (230° to 248° F.) until no more water escapes. For this purpose the drying closets in use in chemical laboratories may be utilized. If, after this treatment, the cakes show no edge cracks, the cement is to be considered in general of constant volume. If such cracks do appear, the cement is not to be condemned, but the results of the decisive test with the cakes hardening on glass plates under water must be waited for. It must, however, be noticed that the heat test does not admit of a final conclusion as to the constancy of volume of those cements which contain more than 3 % of calcium sulphate (gypsum) or other sulphur combinations.

For making the final test, the cake made for the purpose of determining the time of setting, for slow setting cements, is placed under water after the lapse of twenty-four hours, but, at all events, not until after it is set. For quick setting cements this can be done after a shorter period. The cakes, especially those of slow setting cements, must be protected against draughts and sunshine until their final setting. This is best accomplished by keeping them in a covered box lined with zinc, or under wet cloths. In this manner the formation of heat cracks is avoided, which are generally formed in the center of the cake and may be taken by an inexperienced person for cracks formed by blowing.

In order to obtain concordant results in the tests, sand of uniform size of grain and uniform quality must be used. This standard sand is obtained by washing and drying the purest quartz sand obtainable, sifting the same through a sieve with

60 meshes per square centimeter (387 per sq. in.), thereby separating the coarsest particles, and by removing from the sand so obtained, by means of a sieve of 120 meshes per square centimeter (774 per sq. in.), the finest particles. The diameter for the wires of the sieves shall be 0.38 mm. and 0.32 mm. (.015 in. and .013 in.) respectively. Since not all quartz sand, even under the same method of treatment, gives the same resulting strengths in the mortars, one must know whether the standard sand at one's disposal gives concordant results with the standard sand furnished by the German Society of Cement Manufacturers and also used at the Royal Testing Station at Berlin (Charlottenburg).

For each test, in order to obtain correct average results, at least 6 test pieces are to be made. Tensile test pieces can be made made either by hand or by machinery.

HAND WORK.

On a metal or thick glass plate 5 sheets of blotting paper soaked in water are laid, and on these are placed 5 molds wetted with water; 250 grammes (8.75 oz.) of cement and 750 grammes (26.25 oz.) of standard sand are weighed and thoroughly mixed dry in a vessel. Then 100 cubic centimeters (100 g. or 35 oz.) of fresh water are added, and the whole mass thoroughly mixed for 5 minutes. With the mortar so obtained the molds are at once filled, with one filling, so high as to be rounded on top, the mortar being well pressed in. By means of an iron trowel 5 to 8 centimeters (1.96 in. to 3.14 in.) wide, 35 centimeters (13.79 in.) long, and weighing about 250 grammes, (8.75 oz.) the projecting mortar is pounded first gently and from the side, then harder into the molds until the mortar grows elastic, and water flushes to the surface. A pounding of at least one minute is absolutely essential. An additional filling and pounding in of the mortar is not admissible, since the test pieces of the same cement shall have the same densities at the different testing stations. The mass projecting over the mold is now cut off with a knife, and the surface smoothed. The mold is carefully taken off and the test piece placed in a box lined with zinc, which is to be

provided with a cover, to prevent a non-uniform drying of the test pieces at different temperatures. Twenty-four hours after being made, the test pieces are placed under water, and care has to be taken that they remain under water during the whole period of hardening.

MACHINE WORK.

After the mold, provided with a guide mold, has been clamped, by means of set screws, on the bed-plate of the pounding machine, for each test, 180 grammes (6.3 oz.) of the mortar, made as above, are placed in the mold and the iron follower is set in. By means of Böhme's hammer apparatus, with a hammer weighing 2 kilogrammes, (4.4 lbs.), 150 blows are struck on the follower.

After the guide mold and follower have been removed, the test piece is scraped off, smoothed, taken with the mold from the bed-plate and for the rest treated as for the hand work. By accurately following the directions given above, hand and machine work give well concording results. In all cases of doubt the machine work is to be decisive.

COMPRESSIVE TESTS.

In order to obtain concordant values in compression tests at different stations, machine making is necessary. Four hundred grammes (14 oz.) of neat cement, and 1,200 grammes (42 oz.) dry standard sand are thoroughly mixed dry in a vessel, and 160 cubic centimeters (5.6 oz.) of water are added thereto, and then the mortar is thoroughly mixed for 5 minutes, Of this mortar 850 grammes (30 oz.) are placed in the cubic molds, provided with guide mold, and the mold is then screwed on the bed-plate under the pounding machine. The iron follower is placed in the form and by means of Böhme's trip hammer, 150 blows are struck, by a hammer weighing 2 kilogrammes (4.4 lbs.).

After removing the guide mold and follower, the test piece is smoothed off, with the mold from the bed-plate, and for the rest treated as for hand work, as given above.

MAKING TEST PIECES OF NEAT CEMENT.

The inside of the molds is slightly oiled, and the same are placed on a metal or glass plate without blotting paper. One thousand grammes (35 ozs.) of cement are weighed out, two hundred grammes (7 ozs.) of water are added, and the whole mass thoroughly mixed for five minutes (best with pestle). The forms are well filled (rounded), and then proceed as for hand work, as given above. The molds can only be taken off after the cement has sufficiently hardened. Since, by the pounding in of the neat cement, test pieces of uniform consistency are to be obtained, for finely ground or quick setting cements, the amount of water must be correspondingly increased. The volume of water used is always to be stated in giving the strength obtained.

TREATMENT OF TEST PIECES AT TIME OF TESTING.

All specimens are to be tested directly after their removal from the water. Since the time of testing is of influence on the result in tensile tests, the increase of load shall be one hundred grammes (3.5 oz.) per second. The mean of the four best results shall be considered the final tensile strength. In testing compression pieces, the pressure is always to be exerted on two side faces of the cube, but not on the bottom or top. The mean of the four highest tests shall be considered as the final compressive strength.

ABSTRACTS FROM FRENCH SPECIFICATIONS FOR PORTLAND CEMENT.

CHEMICAL ANALYSIS.

The cement must not contain more than 1 % of sulphuric acids or sulphides in determinable proportion. Cements containing more than 4 % of ferric oxide, or in which the ratio of the combined silica and alumina to the lime is less than 0.44, are to be regarded as doubtful.

MIXING THE MORTAR.

In mixing the mortar for testing, sea water is specified, and

both air and water are to be maintained at a temperature of 15° to 18° C. (59° to 64.4° F.) during the continuance of the experiments. The quantity of water is ascertained by a preliminary experiment, and the four following tests are given to serve as an indication whether the proportion of water added is correct:

1. The consistence of the mortar should not change if it be gauged for an additional period of three minutes after the initial five minutes.

2. A small quantity of the mortar dropped from the trowel upon the marble slab from a height of about 0.50 metre (1.64 ft.) should leave the trowel clean, and retain its form approximately without cracking.

3. A small quantity of the mortar worked gently in the hands should be easily molded into a ball, on the surface of which water should appear. When this ball is dropped from a height of 0.50 metre (1.64 ft.) it should retain a rounded shape without cracking.

4. If a slightly smaller quantity of water be used, the mortar should be crumbly, and crack when dropped upon the slab. On the other hand, the addition of a further quantity of water—1 to 2 % of the weight of the cement—would soften the mortar, rendering it more adhesive, and preventing it from retaining its form when allowed to fall upon the slab. It is recommended to commence with a rather smaller quantity of water than may be ultimately required, and then to make fresh mixings with a slight additional quantity of water.

The mortar is to be mixed with a trowel for five minutes upon a marble slab.

STRENGTH.

The form of briquette and method of molding are the same as required by the German specifications; the breaking section is 5 square centimetres (0.775 sq. in.). Six briquettes are broken after an interval of 7 days, six after 28 days, and the remaining six after 84 days. The mean of the three highest figures of each series of tests is taken as the tensile

strength of the cement under examination. The minimum strength specified for the neat cement in 7 days is 20 kilogrammes per square centimetre (284.5 lbs. per sq. in.); in 28 days, 35 kilogrammes per square centimetre (49.8 lbs. per sq. in.); and at least 45 kilogrammes per square centimetre (640 lbs. per sq. in.) in 84 days. If, however, the strength in 28 days is not more than 5 kilogrammes per square centimetre (71.12 lbs. per sq. in.) in excess of that at 7 days, then it must be at least 55 kilogrammes per square centimetre (782.27 lbs. per sq. in.) in 28 days, and in any case where this strength is not attained at 28 days it must be exceeded in 84 days

Tests of cement mixed with sand are also specified. The standard sand is produced by crushing quartzite obtained from quarries near Cherbourg, and sifting it through sieves of 64 and 144 meshes per square centimetre (413 and 929 meshes per sq. in.). That which remains between these two sieves is washed and dried, and constitutes the standard sand. Three hundred and seventy-five grammes (13.25 oz.) of this sand is mixed with 125 grammes (4.41 oz.) of cement, and water is added in the proportion of 12 parts by weight to 100 parts of sand and cement combined. The sand and cement are first carefully mixed in a basin or capsule, then the whole of the sea water is added at once, and the mixture stirred with a spatula for 5 minutes. At the expiration of 7 days the strength of the sand-cement briquettes should be at least 8 kilogrammes per square centimetre (113.78 lbs. per sq. in.), and in 28 days 15 kilogrammes per square centimetre (213.35 lbs. per sq. in.). In 28 days the strength should exceed that at 7 days by 2 kilogrammes per square centimetre (28.45 lbs. per sq. in.). In 84 days the strength must be greater than at 28 days, and at least 18 kilogrammes per square centimetre (256 lbs. per sq. in.). The 84-day tests are only considered indispensable for those cements which may have stood the two previous tests; but if, while the cement is in store, the 84-day tests should be unsatisfactory, it may be rejected.

FINENESS OF GRINDING.

The degree of fineness to which the cement must be ground is not specified, it being considered that very fine grinding increases the strength chiefly during the duration of the tests, and that the subsequent increase of strength is less with fine than with coarse cement.

TIME OF SETTING.

Essentially the same as the German specifications. Any cement commencing to set in less than 30 minutes, or failing to commence to set within 3 hours, is to be rejected; and the final set must have taken place within 12 hours. In each case the time is reckoned from the moment the water is poured upon the cement.

Austrian Specifications for Fineness and Strength of Cement.

FOR PORTLAND.

Fineness, not more than 20 % to be left on sieve of 5,806 meshes per square inch. Tensile strength (1 part cement and 3 parts sand), 1 day in air and 6 in water, 113.78 lbs. per sq. in.; 1 day in air and 27 in water, 170.68 lbs. per sq. in.

FOR ROMAN.

Fineness, same as for Portland. Tensile strength (1 part cement and 3 parts sand), for quick setting cements (taking 15 minutes, or less, to set), 1 day in air and 6 days in water, 23 lbs. per sq. in.; 1 day in air and 27 in water, 56.9 lbs. per sq. in. For slow setting cements (taking more than 15 minutes to set), 1 day in air and 6 days in water, 42.6 lbs. per sq. in.; 1 day in air and 27 in water, 85.3 lbs. per sq. in.

English Specifications for Portland Cement.

The following is a summary of the specifications used by Mr. Henry Faija, an accepted English authority:

Fineness is to be such that the cement will all pass through

a sieve having 625 holes (25^2) to the square inch, and leave only 10 % residue when sifted through a sieve having 2,500 holes (50^2) to the square inch.

EXPANSION OR CONTRACTION.

A pat made and submitted to moist heat and warm water at a temperature of about 100° F. shall show no sign of blowing in 24 hours.

TENSILE STRENGTH.

Briquettes of slow setting Portland, which have been gauged, treated, and tested in the prescribed manner, to carry an average tensile strain, without fracture, of at least 176 lbs. per sq. in. at the expiration of 3 days from guaging; and those tested at the expiration of 7 days to show an increase of at least 50 % over the strength of those at 3 days, but to carry a minimum of 350 lbs. per sq. in.

For quick setting Portland, at least 176 lbs. per sq. in. at 3 days, and an increase at 7 days of 20 to 25 %, but a minimum of 400 lbs. per sq. in. Very high tensile strengths at early dates generally indicate a cement verging on an unsound one.

CHAPTER VI.

THE CHEMICAL PROCESSES CONCERNED IN THE HARDENING OF HYDRAULIC CEMENTS.

By LAUNCELOT ANDREWS, Ph.D.

I.

CLASSIFICATION.

Under the general term "cement" the engineer understands certain mixtures which possess the property in common of hardening to a strong mass when brought into contact with water. We may conveniently divide the practically important cements into three groups: first, those containing silicates as an essential constituent, such as Portland cement and the hydraulic limes; second, those consisting chiefly of neutral salts capable of combining with water of crystallization to form a hard mass, such as plaster of Paris, either used alone or together with alum, etc.; third, substances which form basic salts when treated with water, such as mixtures of magnesia with magnesium chloride, or of plaster of Paris with lime; fourth, mortar, or mixtures of lime with substances such as sand, upon which it has no action. In this last class, the absorption of carbonic acid from the air plays an important part in the final hardening.

II.

THE CAUSE OF THE "SETTING" OF CEMENTS IN GENERAL AND CONDITIONS AFFECTING IT.*

The setting of a cement is, in general, a complex process,

*The following section of this article is with minor changes reprinted from a paper by Andrews and Spanutius published in Vol. I, No. 2, p. 41 of the Transit, and now out of print.

partly chemical in its nature and in part mechanical. Broadly stated, the chemical changes which occur may be said rather to afford opportunity for the mechanical changes which result in hardening, than themselves to cause the hardening. The chemical changes are therefore susceptible of wide variation without materially influencing the result.

In all cases a dry cement consists of grains with interspaces between them and in contact at but few points. When treated with water, a portion of these grains dissolves and is then redeposited, in combination with water, in a crystalline form, between the grains, binding them together at numerous points of contact.

The solidity of the resulting mass depends; *first*, on the area of contact between the grains; *second*, on the original volume occupied by the cement, that is to say, upon its density; *third*, upon the increase of volume which results from the combination with water; *fourth*, upon the inherent tenacity of the material binding the grains together, the latter varying with its chemical composition.

The area of contact between the grains will be increased by pressure, which tends to bring the grains closer together, and will also be increased by the increase of volume which the cement undergoes when combining with water. In an ideal cement, this increase of volume, would be just equal to the volume of the empty spaces existing between the grains while the cement was dry. Any increase of volume beyond this point will simply tend to tear apart the partially solidified mass, causing a crumbling of the cement. A similar effect will be produced if, in consequence of a too rapid combination with water, the temperature should rise sufficiently high to produce steam.

That the crumbling which calcined lime undergoes on being slaked is simply a result of the mechanically disintegrating action of the evolved steam, may be shown by submitting a piece of burnt lime to the action of dry steam, carefully avoiding all condensation of water to the liquid state.

Under these conditions the lime will rapidly slake, without

cracking or crumbling, forming a stony mass of calcium hydrate. The tearing action of the steam may likewise be counteracted by outside pressure; thus, if a steel tube perforated with a number of fine holes be completely filled with burnt lime and both ends closed by steel plugs and the entire arrangement immersed in water, the contents will gradually become converted to a rocky cylinder of calcium hydrate. Since, in practice, it is impossible to adopt either of these devices, there is no resource left but to so adjust the composition of the cement as to cause its combination with water to take place so slowly that the heat will escape nearly as fast as produced; an injurious rise of temperature being in this way prevented. Incidentally a further advantage accrues from retarding the act of hydration. The processes of crystallization, to which, as we have seen, the hardening of all cements is directly due, takes place but slowly. If, therefore, the hydration takes place rapidly, the crystallization will be imperfect and many of the individual crystals will be too minute to bridge over the distance between contiguous grains of cement. Under these circumstances incomplete adhesion will follow and a weak or friable cement will be the result. Now it is evident that a cement consisting of coarse grains should combine with water more slowly than one consisting of fine grains, in order to give a product of equal tenacity, because in the former case the interstices are larger and the crystal formation must be larger and more complete in order to bridge over the interspaces. As a practical consequence, if a very rapidly setting cement is needed for any particular purpose, it must be very finely ground.

In some cements, of which plaster of Paris may be taken as the type, water simply combines with some constituent of the cement, converting it into a more bulky and crystalline hydrate. In others, various chemical reactions occur in addition to the mere combination with water, giving rise to new compounds. Thus in ordinary mortar, carbonic acid is taken up from the air, forming calcium carbonate, to which is due the great solidity and hardness of very old mortar.

The hardening of Portland cement is dependent upon the combination of water with certain substances produced from the constituents of cement by the action of the water and is accordingly a complex process.

III.

COMPOSITION AND CHARACTERISTICS OF PORTLAND CEMENT.

Portland cement is a product formed by sintering* together materials containing only clay and lime, and finely pulverizing. It is allowable to add not more than 2 per cent. of plaster of Paris, or of some similar substance, for the purpose of rendering the setting of the cement slower. Beyond this, all additions or substitutions are to be regarded as *adulterations*.†

An ideal cement of this class should possess the following composition:

Lime, . . .	62.2 %
Silica, . . .	28.2
Alumina, . . .	9.6
	100.0

But up to about a third of the alumina may be replaced by ferric oxide, which would correspond to the composition:

Lime, . . .	61.7
Silica, . . .	27.4
Alumina, . . .	7.5
Ferric oxide, . .	3.4

The following table shows how nearly the actual Portland cements approach in composition the above ideal. The maxima and minima given are derived from analyses of nine representative English and German manufacturers.

* That is, heating to the temperature of incipient fusion.

† Definition adopted by the Association of German Portland Cement Manufacturers.

	MAXIMUM	MINIMUM
Lime,	62	57
Silica,	24	19
Alumina,	8.8	5.2
Ferric oxide,	5.0	2.0
Magnesia,	3.5	0.3
Potash,	1.0	0.4
Soda,	0.8	0.4
Sulphuric acid,	1.0	—
Sand, etc.,	2.9	1.0
Carbonic acid,	1.9	0.0
Water,	1.5	0.0

Portland cement should not have a lower specific gravity than 3.00 in the case of long stored samples, nor lower than 3.12 when freshly ignited. The best qualities exhibit a density notably higher than this, viz.: 3.14 to 3.15.

It should show a loss of weight upon ignition to a bright red heat, of from 0.34 per cent. to 2.6 per cent.,* a greater loss showing imperfect manufacture or too great age.

One gram upon shaking with 100 c. c. water should impart to the latter not more than 4 per cent. (on the weight of the cement) of lime. The total magnesia should not exceed 3 per cent.

Adulteration with blast furnace slag may be detected in the following simple way: if a pure Portland cement be shaken up with water and then acidified with hydrochloric acid and allowed to stand, it will soon settle, leaving the water clear. If, however, slag be present, sulphur will separate under the circumstances mentioned and will impart a milkiness or opalescence to the water which will remain for many hours.†

A, perhaps, more positive indication of the same sophistication is afforded in the course of chemical analysis by the reducing action of ferrous compounds always present in slag. Fresenius has shown that 1 gram of an adulterated cement should not be capable of reducing more than .0028 grams of

*Post, Chemisch-Technische Analyse.

†Fresenius.

potassium permanganate, whereas a slag cement has on an average a ten times more powerful reducing action.

The presence of more than 66 per cent. of lime is likely to cause the cement containing it to crumble or crack during the setting.

This action is due to the increase of volume which lime undergoes in slaking and consequent disruption of the network of crystals the formation of which is the controlling factor in the setting. Nevertheless, the limit given is valid only for cements of otherwise normal composition. The injurious action of an excessively high percentage of lime may be to a certain extent counteracted by a high percentage of silica or also by calcining the cement at a higher temperature than usual. In either case the setting will be slower and the injurious action of the lime less apparent.

On the other hand, magnesia enhances the tendency to swell and crumble, hence the 3 per cent. limit given above.

The influence of the form and size of the cement grains upon the hardening qualities is of the greatest importance, as must be evident from the considerations advanced in the previous section.

All grains so large as not to pass a sieve of 75 meshes to the linear inch are to be regarded as inert or wholly passive constituents.

They should not constitute more than 20 per cent. of the total weight. The hardness and tenacity of the product increases steadily with increasing fineness up to the extreme limits which have been investigated, that is of grains so fine that all will pass a sieve of 175 meshes to the linear inch.

The form of the grain depends upon the temperature at which the mass has been sintered and upon the composition. It is, therefore, difficult to separate the influence of this factor from that of others.

It may, however, be said that flattened, slaty-grained cements, such as are produced by thorough sintering at a high temperature, are better than those having rounded grains, which are formed at lower temperatures, and the question may

be left open whether the superiority of the first kind is due directly to the form of grain or to the more perfect burning, with the probabilities in favor of a concurrence of both causes.

IV.

CHEMICAL PROCESSES OCCURRING DURING THE HARDENING OF PORTLAND CEMENT.

Le Chatelier has discovered by examining thin sections of burnt Portland cement with the polarizing microscope, the presence of calcium aluminate, $Ca_3Al_2O_8$ and of a calcium ferrialuminate, $Ca_3(Al\ Fe)_4O_{11}$ and of calcium metasilicate, $Ca\ Si\ O_3$. Calcium orthosilicate, $Ca_2Si\ O_4$, and the aluminate, $Ca_2Al_2O_5$, are also present (Landrin and others).

When the cement is mixed with water, the calcium orthosilicate and the calcium aluminate combine with water to form a hydrated calcium silicate, $H_2Ca\ Si\ O_4$ and $(H\ O\ Ca\ O)_3Al$, hydrated calcium aluminate, which latter at once begins to crystallize out in the form of felted needles which extend in every direction and are the first cause of the setting of the cement.

$$3Ca_2Si\ O_4+Ca_3Al\ O_8+6H_2O =$$
$$2(H\ O\ Ca\ O)_3Al+3H_2Ca\ Si\ O_4.$$

At the same time a much slower process begins which consists in a gradual crystallizing of the hydrated calcium silicate and in the hydration of that portion of the silicates of lime mentioned above which does not react with the aluminate. To this tardy change is due the secondary hardening of the cement, a process which takes place best under water. Lastly, carbonic acid is absorbed from the air, converting any excess of lime into carbonate and still further contributing to the hardness of the product and to its insolubility in water. The amount of carbonate of lime formed in this way in old cements sometimes exceeds 12 per cent.*

The temperature of the water with which the cement is made up has a great influence upon the rapidity of the harden-

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*Feichtinger, Dingl Journal, 152, pp. 40, 108.

ing and hence upon the tenacity finally attained. The chemical reactions taking place in this process are, like all others, greatly accelerated by elevation of temperature. This diminishes the strength of the product because crystallization is essentially slow, and if the crystals of hydrated lime aluminate do not have time to form completely, their interlacing network, upon which the toughness of the mass so greatly depends, will not be properly developed. The addition of gypsum to the cement renders the setting slow by reducing the solubility of the calcium aluminate but, for the same reason, it induces the formation of smaller and, therefore, less efficient crystals and hence acts injuriously when present in more than certain very small quantities.

CHAPTER VII.

Cement Testing Machines and Stone Crushers.

CEMENT TESTING MACHINES.

The different types of cement testing machines in general use are shown in Figs. 27, 28, 29, 30.

The object of the machines is to bring a steadily increasing

Fig. 27. Riehle Brothers' 1,000 pound Cement Tester.

strain upon the specimen up to the point of rupture, and in addition to this, the machine must be so designed that the amount of strain, to which the specimen is subjected, may be measured in pounds or some unit of weight. In the machines shown in Figs. 27 and 28, the strain is applied to the specimen

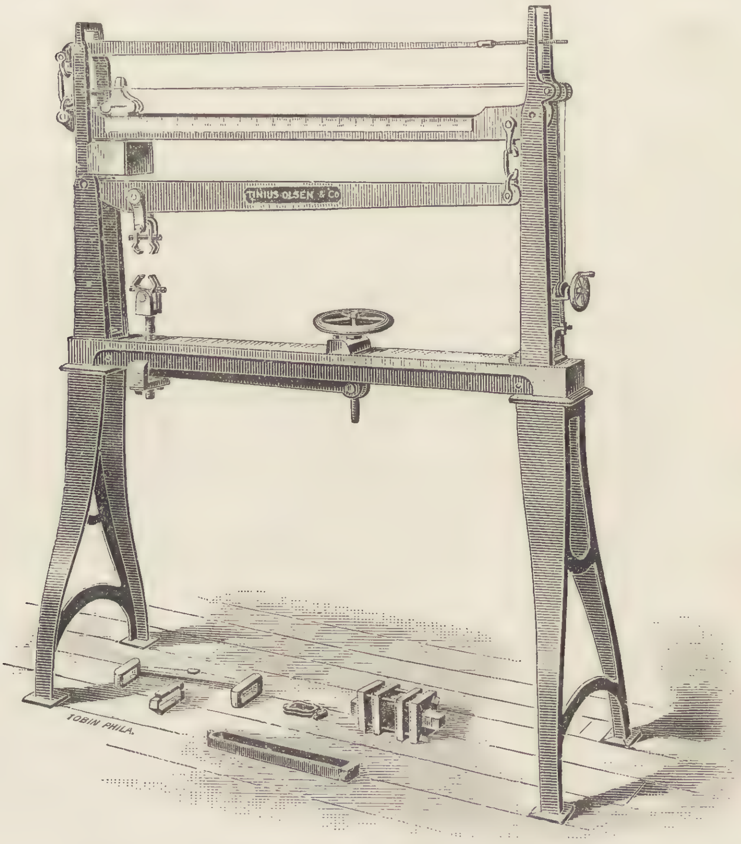

FIG. 28. TINIUS OLSEN CEMENT TESTER.

by means of a screw worked by a worm gear. The amount of strain is measured by a weight sliding upon a bar similar to the long arm of a steelyard. This bar being kept balanced during the entire test, the amount of strain upon the specimen at any time is indicated by the position of the sliding weight.

The position of the specimen and the arrangement of clips can be seen in the figures. Figs. 29 and 30 show a different type of machine. In machines of this type the strain is applied to the specimen, not by means of a screw and worm gear, but by means of a gradually increasing weight at the

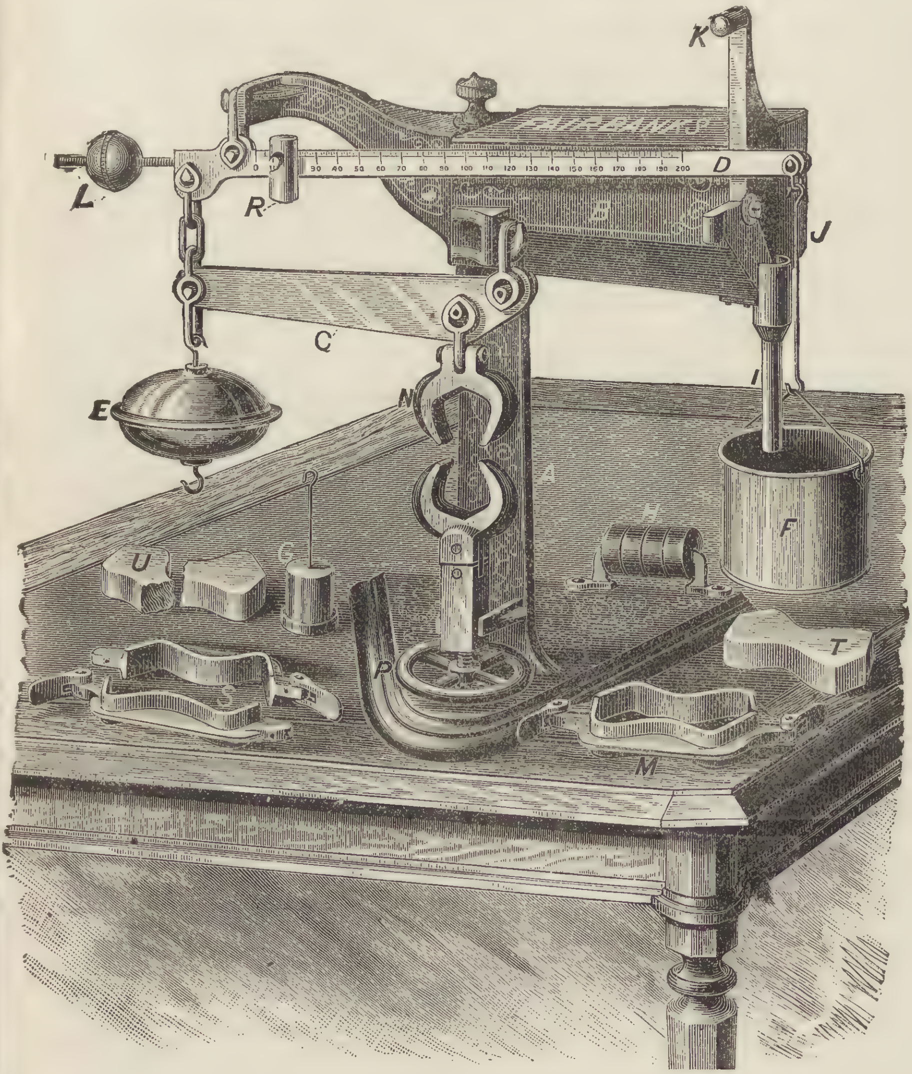

FIG. 29. FAIRBANKS' CEMENT TESTER.

end of the long lever. In Fig. 29, the pan *F* hangs at the end of the long lever *D*. The hopper *B* is filled with fine shot. The briquette is put in place and the levers balanced. A valve in the hopper is opened and the shot runs through the outlet *I* into the pan *F*. The rapidity with which the shot runs into the pan can be regulated. The weight in the pan increases and with it the strain on the specimen, until the point of rupture is reached. The specimen breaks, the arm *D* falls and shuts off the shot. The pan *F* is then removed, hung on the hook below *E* and weighed by means of the sliding weight *R* on the lever *D*. From this may be obtained at once the amount of strain under which the specimen broke. Fig. 30 shows the outline of a similar type of machine.

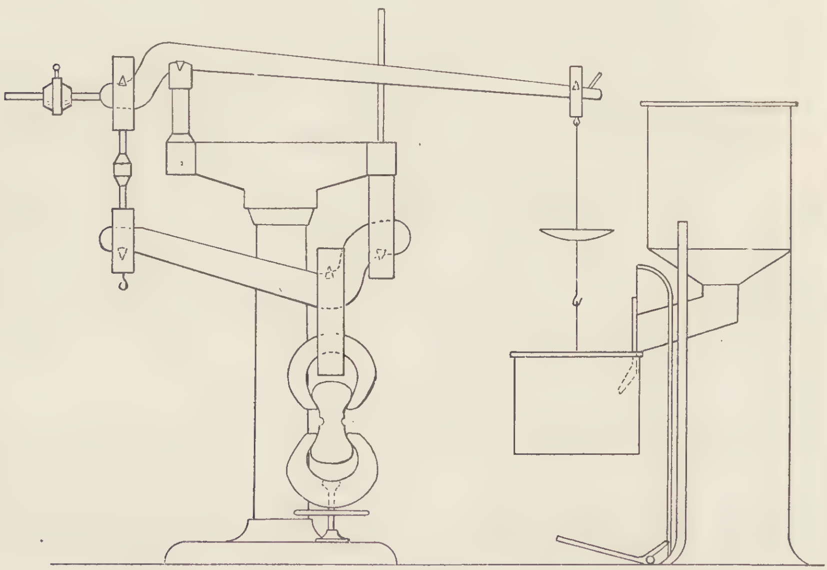

FIG. 30.

In regard to the relative merits of the different machines illustrated, each investigator must decide for himself. Most accurate and satisfactory results may be obtained with either type. Any of these direct lever machines are to be preferred to spring balances.

There are a number of hydraulic machines used in Europe

that give good results, but they are more expensive than the lever machines, and possess no advantages over them, within the limit of power required. The capacity of the ordinary cement testing machine is 1,000 pounds. Full descriptions

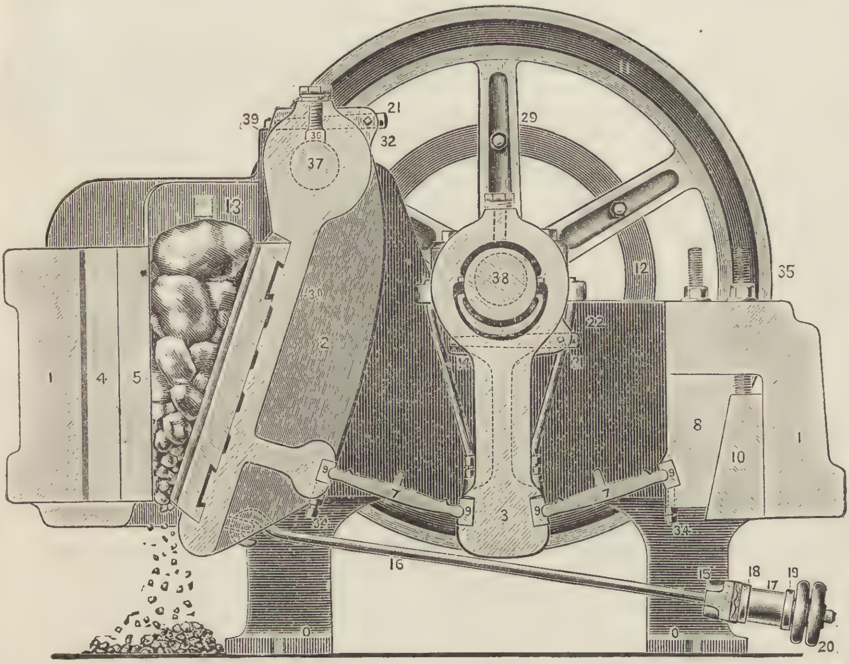

FIG. 31. SECTIONAL VIEW OF FARREL MARSDEN STONE CRUSHER.

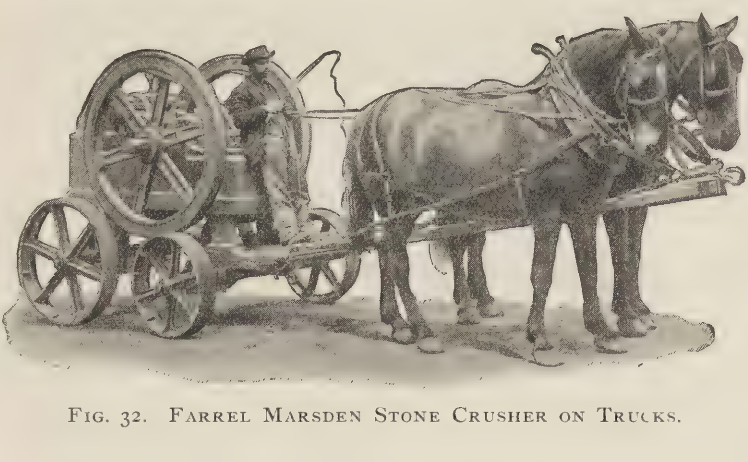

FIG. 32. FARREL MARSDEN STONE CRUSHER ON TRUCKS.

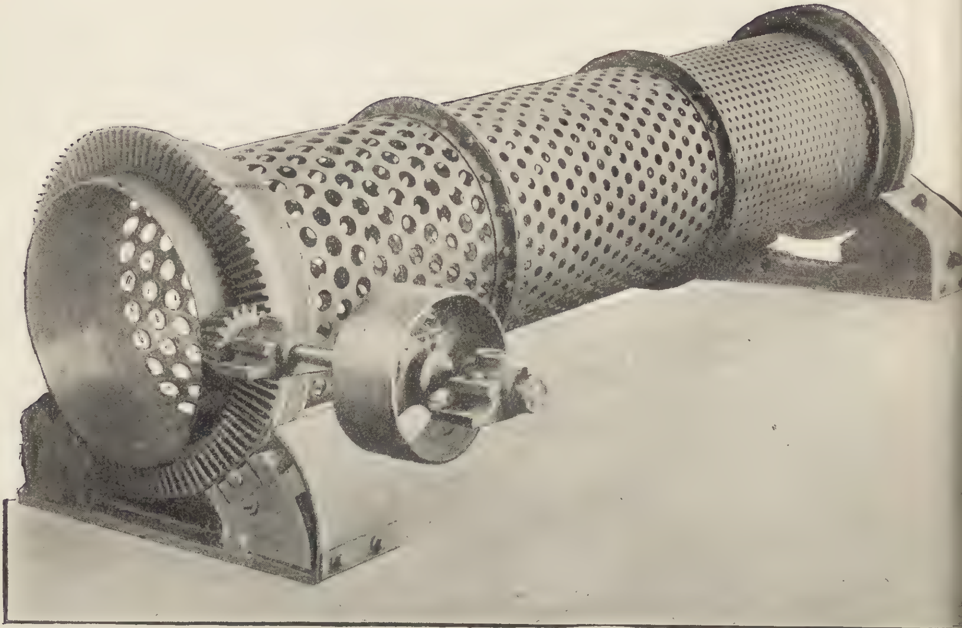

FIG. 33. FARREL MARSDEN REVOLVING SCREEN FOR BROKEN STONE.

of these machines, with details, cost, etc., may be obtained from the manufacturers. They also furnish complete outfits for cement testing laboratories.

STONE CRUSHERS.

The type of stone crusher that has been in most general use for the last thirty years is what is known as the Blake or Marsden. Fig. 31 shows a sectional view of this type as now made by the Farrel Marsden Foundry Company, Ansonia, Connecticut.

It is a comparatively cheap machine for the amount of work it can do, and as the parts are few and strong, the expense for repairs is almost nothing. Where the material to be crushed is strongly laminated the crushing is not done in as satisfactory a manner as with the revolving type. Fig. 32 shows the crusher mounted on wheels, to facilitate its movement from one place to another.

Fig. 33 shows the revolving screen that is furnished when it

is desired to grade the size of the material. The size to which the material is crushed may be regulated by changing the pieces marked *7*, *7*, for similar pieces of greater or less length, and by raising or lowering the wedge *10*.

The following table in regard to size and capacity of the Farrel Marsden crusher is taken from their published catalogue. The experience of the author has shown that the most economical results are obtained when the engines used are 15 to 25 % more powerful than those given in the table.

FARREL MARSDEN CRUSHER—DIMENSIONS, CAPACITIES, ETC.:

	Receiving Capacity	Approximate product of 2-in. stone per hour	Approximate weight	Horse-power	Prices
3	10×4 in.	3 cubic yds.	4,900 lbs.	6	$ 275.00
4	10×7 "	5 " "	7,800 "	12	500.00
5	15×9 "	8 " "	14,500 "	15	750.00
6	15×10 "	9 " "	15,000 "	15	800.00
8	20×10 "	10 " "	17,000 "	20	1050.00

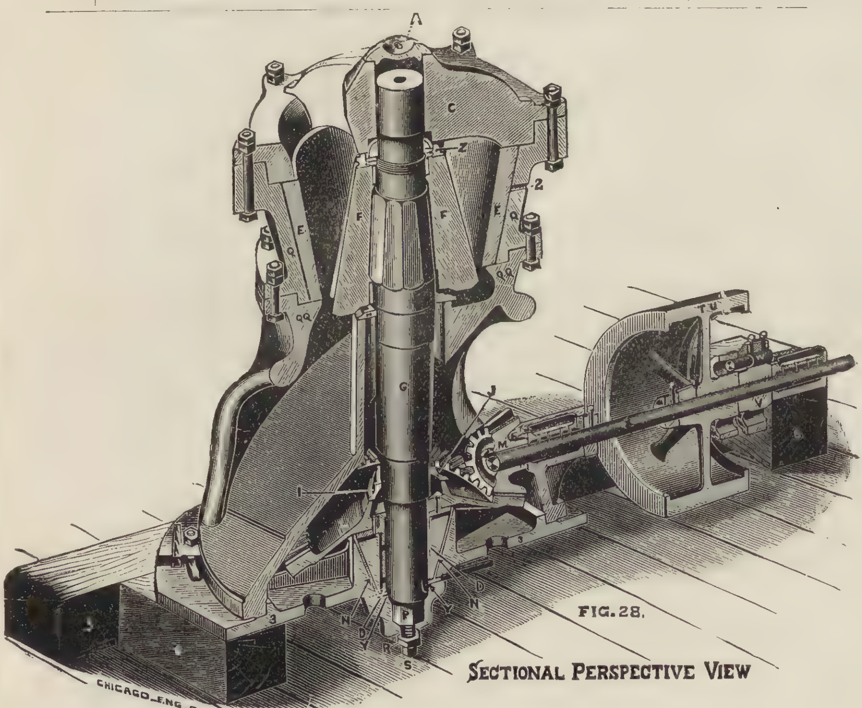

FIG. 34. GATES' ROCK AND ORE BREAKER—SECTIONAL VIEW.

The Gates rock and ore breaker, Fig. 34 shows a sectional view and Fig. 35 a general view. The machine has given satisfaction and great numbers are in use.

GATES' ROCK AND ORE BREAKERS—DIMENSIONS, PRICES, ETC.

SIZE.	Dimensions of each reciving opening about. INCHES.	Weight of Breaker. POUNDS.	Capacity per hour in tons of 2,000 lbs. passing 2½ in. ring, according to character of rock or ore.	Diameter of Hopper. INCHES.	Size engine recommended to drive breaker elevators and screen. Indicated Horse Power.	PRICES.
00	2×4	500		13	1 to 1½	$ 125
0	2×10	3,300	2 to 4	28	4 " 5	400
1	5×12	5,600	4 " 8	42¼	8 " 10	600
2	6×14	7,800	6 " 12	46¼	12 " 15	800
3	7×15	13,800	10 " 20	54½	20 " 25	1,200
4	8×18	21,500	15 " 30	79¾	25 " 30	1,900
5	10×20	27,000	25 " 40	88	30 " 40	2,500
6	11×24	40,500	30 " 60	103	40 " 60	3,500
7½	14×30	65,800	75 " 125	120	75 " 125	6,000
8	18×42	89,000	100 to 150	132	100 " 150	7,000

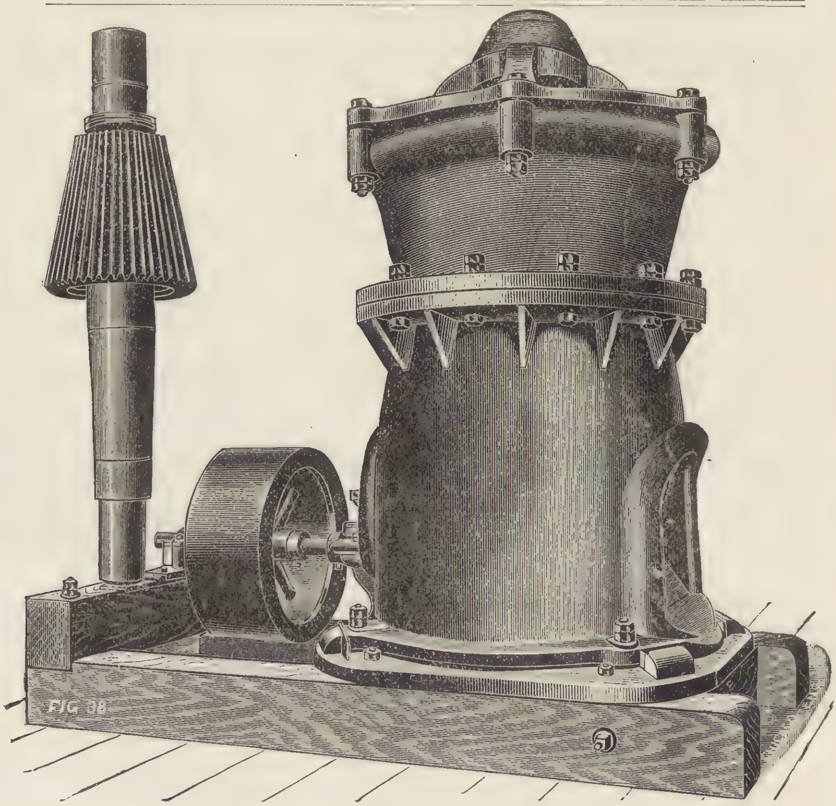

FIG. 36. GATES' ROCK AND ORE BREAKER—GENERAL VIEW.

CHAPTER VIII.

THE USE OF PORTLAND CEMENT.

In engineering construction Portland cement is used in *mortar*, in *concrete*, and in the making of *artificial stone*. It is used either neat or mixed with a certain amount of sand.

Mortar.—From an engineering stand-point mortar may be defined as a building material made by mixing *lime*, *cement*, or *plaster of Paris*, either separately or in any combination, with a certain amount of water, and to this mixture may be added or not certain proportions of sand. The use of mortar is to bind together the stone or brick of which the masonry is constructed.

Lime Mortar.—In the making of lime mortar the use of sand is indispensable, if good results are looked for. The reason of this is that the lime shrinks so much in setting, that if lime and water alone were used, the mortar would detach itself entirely from the adjacent stones or brick, and no bond would result. By the introduction of a large proportion of sand the percentage of this shrinkage is very much decreased. The sand, being a perfectly inert mass, has no tendency to either expand or contract. Another advantage attending the use of sand in the lime mortar is its cheapness. The bulk of mortar is much increased by the addition of sand, and this increase gained at a less cost than if lime alone had been used.

Lime mortar is the cheapest form of mortar that can be made. This is due to the small first cost of the lime, and then to the fact that the lime expands to three or four times its original bulk in slaking.

The utility of lime mortar is limited, owing to the very

slight strength that it attains under the most favorable circumstances, and from the fact that it cannot be used to advantage in damp places. Its principal use is in the shape of plaster and in laying up ordinary brick walls that are to be subjected to no extraordinary strain, and are in such a location as to be comparatively dry.

The use of lime mortar in ordinary foundations, cellar walls, retaining walls, and in all masonry subjected to great strain or moisture has been superseded by the use of some form of cement mortar. Also in the construction of any masonry in which the thickness is such as to exclude all possibility of the air penetrating the interior. Under all ordinary circumstances the mortar is made of some brand of *natural cement* and the use of *Portland cement* is reserved for the more important points. There has been much discussion as to which cement was the most economical for use, natural cement or Portland cement. Excepting in a very few cases, the subject does not appear to us as admitting of any discussion. An examination of the diagrams in Chapter IX. will show at once the great superiority in strength that Portland cement possesses and the question turns upon the amount of strength and certain other qualities required in the mortar.

The effect of sand in reducing the strength of mortar is relatively about the same in each cement. The practice of adding an exorbitant amount of sand to Portland cement, in order to reduce the cost of the mortar, is bad. The resulting mortar is porous, affected by the weather, and liable to disintegrate. Of course, if sufficient sand is added to Portland cement, the cost of the mortar may be reduced to that of natural cement mortar, and possibly the Portland cement mortar may still be the stronger in any laboratory tests. But it will not be as durable. When the strength required is no more than can be reached by mortar made of natural cement and an ordinary amount of sand, the natural cement should be used; and when more strength is required, the Portland cement should be used. What has just been said applies merely to the ultimate strength of the mortar. There

is one other point, however, that must be frequently considered, viz.: the setting properties of the cement.

The Portland cements are usually what are termed "slow setting," while the light-burned natural cements are "quick setting." This property may in some cases settle the question as to which cement should be used. It should be remembered, however, that there is a great variation in the setting qualities of the different Portland cements, and also in the same brands at different ages. Usually, the older a Portland cement is, the slower setting it is, provided it has been properly stored.

Many of the best Portland cement factories can furnish, upon demand, either a *slow* or *quick* setting cement that will meet the standard specifications for strength.

On the other hand, the natural cements may be made slow setting by the addition of a little lime paste to the mortar.

The following proportions make a good slow setting mortar:

1 part lime.
2 parts natural cement.
9 " sand.

By the addition of a small amount of plaster of Paris to either natural or Portland cement mortar the setting is very much hastened, and the ultimate strength of the mortar not affected. The amount of plaster of Paris used should not exceed 3 %. There are very few conditions under which a quick setting cement is absolutely necessary, and the requirements as to ultimate strength should usually decide the brand of cement to be used. When a slow setting cement may be used it possesses many advantages. The mason has more time in which to do his work, and therefore it is better done. In the use of the quick setting cements, the mortar can only be mixed in small quantities, and even then there is danger that it will set before being used, and thus have to be thrown away.

There is one thing that must be carefully guarded against in all work with cement. There seems to be a general tradition, believed by many masons, that the mortar made

from certain cements is improved by allowing it to partially set, and then regauging it with more water and reworking it. Nothing could be more injurious to the mortar. The amount of injury that results from this depends entirely upon to what degree the mortar has been allowed to set before it is reworked.

The setting of the cement is caused by the formation of needle-like crystals, shooting out in every direction from each grain. These crystals bind the whole mass together, and the beginning of the formation of these crystals is the beginning of the so-called setting. If the cement is reworked after the formation of these crystals commences, the crystals are broken, the process of crystallization interfered with, and the ultimate utility of the mortar very much reduced. To the mason, in the handling of the mortar, there is some advantage in this reworking of it. A mortar made of a quick setting cement must be handled quickly and mixed in small quantities. It does not work "smoothly," but is apt to be harsh and brash. By allowing this incipient set to take place and then reworking it, the mortar becomes "smooth working" and slower setting. The reason why it is apparently slower setting is evident. A portion of its setting qualities has been destroyed, and if this so-called incipient set is continued a sufficient length of time, and then the mortar reworked, a mortar may at last be obtained that will have no setting properties at all.

The regauging of mortar should never be allowed under any circumstances. If the mortar sets too quickly and works "brash," the evil can be remedied by the introduction of a small amount of lime, and the quality of the mortar not materially affected.

Sand.—The strength of the mortar depends not only upon the strength of the cement, but also upon the quality of the sand and the relative amount of water used. The sand should be clean and sharp. River sand is often water worn and the grains rounded; such sand does not make as good mortar as sand having angular grains. Bank sand is the best when it is not mixed with earth or clay. If the grains are covered with a deposit of earth or clay, then the cement does not come

in direct contact with them and the resulting mortar is inferior in quality. The requisite qualities of good sand have been well understood from the earliest times. The following specifications for sand were written by Marcus Vitruvius Pollio for the benefit of the Roman Augustus, about the year 25, B. C., and may be regarded as a standard to-day.

"In buildings of rubble work it is of the first importance "that the sand be fit for mixing with the lime, and unalloyed "with earth. . . . . . . The best . . . . is that "which, when rubbed between the fingers, yields a grating "sound. That, also, which is earthy, and does not possess "the roughness above named, is fit for the purpose, if it "merely leave a stain or any particles of earth on a white "garment, which can be easily brushed away. If there be "no sand pits where it can be dug, river sand or sifted gravel "must be used. Even sea sand may be had recourse to, "but it dries very slowly; and walls wherein it is used must "not be much loaded, unless carried up in small portions at "a time. It is not, however, fit for those walls that are to "receive vaulting. . . . . . If sand have been dug a "long time, and exposed to the sun, the moon, and the rain, "it loses binding quality and becomes earthy. . . . ."*

In regard to Vitruvius' specifications for lime and cement, they would hardly pass for standard to-day. Although considering the material with which he had to do, it is surprising how well he understood the results that would obtain. The course of reasoning which he follows in accounting for these results is most ingenious and plausible, although totally incorrect. It will well repay any engineer or architect to read this treatise, and many of our architects of to-day would do well to follow some of the rules he laid down, although they may smile at the course of reasoning he followed, in proving his conclusions.

But Vitruvius aside, the sand should be sharp, angular and clean. The coarseness of the grain that is desirable depends upon the character of the work to be done. But where

*From Gwilt's Vitruvius. Priestly and Weale, London, 1826.

merely strength is required a moderately coarse grain, with a mixture of finer grain, gives the best results. When a fine finish is required the grain should be smaller and possibly less sand used.

In testing the mortar for any particular work, it should be tested with the sand that is to be used, and then tested with the standard sand, crushed quartz or glass. By this method of treatment, not only will the value of the cement be obtained, but also the relative value of the sand that is to be used.

Water.—The amount of water that is used has a great influence upon the quality of the mortar. Within certain limits the less water the better the mortar. Just sufficient should be used to render the mixture as stiff as can be worked with advantage. When more than this amount is used it has a weakening effect upon the mortar.

When there is is a superfluity of water, it simply dries out in time and leaves the mortar porous and liable to disintegration.

Mixing.—In mixing mortar the sand and cement used should be thoroughly mixed *dry* and then the proper amount of water added. This mixing is usually done by hand and is done in a mortar box. The two materials are spread out in separate layers and then thoroughly mixed by being turned with shovels or hoes. After the water is added the whole mass is thoroughly mixed and used without loss of time. The stone or brick with which the mortar is to be used must be thoroughly wet before the mortar is applied. In case this is not done, the stone or brick will draw the water from the mortar before setting begins, and the result will be either a very inferior mortar or a mere dust of sand and cement powder that has no binding qualities.

The one thing to be guarded against in the use of cement, is the superfluous use of water. There is very little danger of using too little.

Masons, almost without exception, injure the quality of their mortar by the excessive use of water. This is more particularly the case in the making of concrete, and additional attention will be called to it under that head.

Cement as Plaster.—Cement is not generally used for interior plaster work, but within the last few years a number of patent cements have been put on the market for this purpose.

Nearly all of these cements possess decided advantages over the lime mortar and the difference in expense is very slight. The advantages resulting from their use are, the greater ultimate hardness and durability; the smooth finish that can be given that enables them to be cleaned readily with soap and water; the decrease in time needed to apply them and the rapidity with which they set and dry. Rooms plastered with them can be occupied with safety in much less time than those in which lime mortar has been used. Their cost has been so much reduced that there is no reason why their use should not become general, and they should certainly be used in the interiors of hospitals, where perfect cleanliness is desirable.

The composition of these patent cements is usually some combination of a light-burned natural cement and plaster of Paris. In some cases an over-clayed Portland cement has been used and in others a mixture of plaster of Paris and burnt clay has given most satisfactory results.

CONCRETE.

Among the most important uses to which cement is put, is the making of concrete. It is in this line of work that by far the larger portion of Portland cement is used.

Concrete may be defined, from an engineering stand-point, as a mixture, of sand, broken stones, broken brick, gravel, or any such material, held together by some cementing substance such as lime, natural cement, Portland cement or some patent cement, mixed with the proper amount of water.

The materials comprising concrete, may be divided into two classes, the material to be held together and the material holding it together. The broken stone, brick or gravel is called the *aggregate*, the cementing material is called the *matrix*.

Materials. The materials to be used in the making of concrete depend upon the object for which the concrete is to

be used, the available material and the justifiable cost. The question of available money has too often entered into the question of concrete construction in this country. The result has been that much poor concrete has been used and in most cases has proven a failure. Concrete should not be used unless there is sufficient money to guarantee good, suitable materials and good work.

Good concrete and suitable materials do not of necessity mean the use of the best Portland cement. What is meant, is the use of such a cement and such an aggregate, that the resulting concrete shall attain a strength many times beyond that, that will be required by any future load. Unless this can be done, it is better to use some substitute. In regard to the quality of the cement that should be used, that will depend upon the purpose for which the concrete is to be used, and will be treated of under the different types of concrete. The aggregate must possess the following qualities, to a greater or less extent:

Hardness,	Toughness,	Durability,
Angularity,	Cleanliness.	

The ultimate quality of the concrete depends primarily upon the qualities of the raw material used. The aggregate may be some material such as stone or brick broken to a suitable size or it may be gravel. The necessity of hardness, toughness and durability in the aggregate is self evident and needs no explanation.

Angularity of fracture or structure improves the quality of the concrete as it makes the binding together of the material much firmer and stronger. For this reason broken stone is in many ways preferable to gravel, provided the quality of the materials is equal. The gravel being composed of stones worn more or less smooth and rounded by water, does not offer the hold for the cement that is offered by broken stone.*

*In an abstract from a recent Government Report it has been claimed that the bond between cement mortar and rounded pebbles was stronger than between the same mortar and broken stone. The broken stone must have been of a very inferior quality or some unknown element have entered into the making or testing of the concrete.—AUTHOR.

Whatever material is used for an aggregate there is one condition that is absolutely indispensable, if good results are obtained and that is cleanliness. The aggregate must be clean, and to insure this, it must be freshly excavated if gravel, or freshly broken if stone. Any material that has been exposed for a year or more will deteriorate in value as an aggregate. By cleanliness is meant that, it must be free from dust, dirt, and earthy matter and from any mould or vegetable growth. If the particles of aggregate are covered with dust or dirt of any kind, the cement is thereby prevented from coming in contact with it and the resulting bond is not perfect. Under the head of mixing concrete this subject will be again touched upon.

Size of Aggregates.—Within certain limits the size of the aggregate depends upon the future use of the concrete. For the purposes of foundations and such general work, where the requirement is strength and not artistic effect, the size may vary, but should not exceed, in broken stone, a piece that will pass through an inch and a half ring. With this size as a maximum, the pieces may grade down to the size of a coffee bean. The graduation in the size of the aggregate lessens the amount of cement mortar necessary.

Reducing the Aggregates.—When broken stone or other similar material is used, it is usually broken in a *stone crusher*. The stone crushers used are of the same type as those already described in Chapter VII. The material as it comes from the crusher must be entirely freed from the coating of fine dust with which it is covered. This can easily be done by turning water on it.

Screening.—The broken stone should be screened, as it comes from the crusher. The object of the screening, is not to reduce the material to uniform size, but simply to keep the size of the stone between a maximum and a minimum limit. The finer particles, those smaller than coffee beans, should not be used, and all of the dust should be carefully screened or washed out. As a maximum limit no piece larger than an inch and a half in any direction should be used.

It is *not* desirable that the aggregate should be of uniform size. When of different sizes they pack better and require less mortar to make good concrete. The amount of mortar needed will depend upon the voids between the particles composing the aggregate. It should be sufficient to entirely fill these voids and to give a thorough and complete coating to each particle. In regard to what particular stones make the best aggregate, there is no stone that excels the best qualities of granite or trap. These two varieties, together with deposits similar to the Sioux Falls Quartzite, possess all of the requisite qualities for the making of good concrete. The sandstones are usually much too soft and are not usually con sidered suitable. Some deposits of limestone will make fair concrete. The hardest and toughest varieties. None of it however can be considered first-class and should only be used when no other material is available, and then used with much care. Limestone does not crush well. There is a tendency to powder and also to break into long thin slabs. There is a loss of from 15 to 25% in the stone from these causes and this should be remembered in making any estimate as to quantities needed, or as to probable cost. The breaking of the stone into thin slabs will be obviated by the use of a rotary stone crusher, but the amount of dust and waste will also be very much increased. The fact that limestone is so generally distributed and so cheaply quarried, is the only excuse for its very general use in the making of concrete.

Gravel.—Good, clean gravel, when obtainable, makes a cheap and durable aggregate. The lack of angularity is the one bad quality it usually has. The material of which it is composed is usually hard and durable, and if the quality of the mortar used is sufficiently rich, the resulting concrete is good.

The gravel should be carefully screened and all earthy or loamy material removed. It is not necessary to remove any clean, sharp sand that may be mixed with the gravel. This sand can be used with the gravel and less sand used with the cement in making the mortar.

Hand Broken.—When broken stone is used as an aggre-

gate, it is often broken by hand in the place of being broken by machinery.

This is always the case where a limited quantity of the material is needed, unless it can be purchased already broken from some central supply station. Stone broken by hand possesses some advantages over machine broken stone, The stone can be broken to any required size and this size runs with greater uniformity. There is almost a total absence of dust and much less waste in the stone. Hand broken stone does not require screening.

Where machine broken stone is not available from a central supply, and the quantity needed not large, it should always be hand broken. The great cost of machine broken stone is the first cost of the plant.

After the plant is once in place, and provided there is sufficient material to keep the machine running all the time, it costs less than one-fourth as much to break by machine as it does by hand. But if the arrangements and needs are such that the machine only runs at irregular intervals, the machine crushing may be even more expensive than that done by hand.

As to the cost of the plant, that depends entirely upon the type of crusher used and the capacity of the plant. (See tables in Chapter VII.)

The crusher should always be placed in or near the quarry. There is a loss of from 12 to 25% in the crushing, and of course this loss should be moved as short a distance as possible.

In buying stone, the better method is to buy it by weight. This is more satisfactory to both parties. When stone is bought by the cubic yard, there is always a question as to its measurement and also as to the manner in which it is piled. The weight of a cubic yard of stone must be determined and when this is once done there can be no dispute as to the amount that has been purchased.

One must remember that 1 cu. yd. of solid stone will make about 1.8 cu. yds. of broken stone. The stone loosely piled and broken to a maximum of 2 inch cubes.

This will decrease about 10% when well rammed in place.

Mixing Concrete.—The proportions of the different ingredients that compose the concrete depend upon the character of the ingredients, the character of the concrete required, etc., and are treated of elsewhere. But, whatever the ingredients may be and in whatever proportions they may be used, the quality of the resulting concrete can be very materially affected by the methods used in mixing, and the subsequent manner of manipulation. Where concrete is to be used in comparatively small quantities, it is mixed by hand and this should be done in the following manner: The mixing is usually done in a rough wooden mixing box, not more than 10 or 12 inches deep and 4 feet wide. The length of the box depends upon the amount of material that is to be handled at once and for the working of two men a box about 14 feet long is convenient.

The box should be approximately water tight.

The correct proportions of sand and cement are put into the box and *thoroughly* mixed dry. This mixture is then drawn to the sides and ends of the box and the proper amount of water is poured into the center. The whole mass is then mixed by either hoes or shovels. The amount of water used should be just sufficient to cause the mixture to have the appearance of wet sand. The important point to be guarded against is the excessive use of water. There is comparatively slight danger of using too little.

As soon as the sand, cement and water have been thoroughly mixed, the broken stone or gravel is added.

Care should be taken that the aggregate used is clean. All dust, dirt or earthy material should be carefully washed out and the aggregate should be wet before being put into the mortar. The wetting should be done in such a manner that any surplus water not absorbed by the aggregate may drain away. The aggregate in this condition, is then added to the mortar and the whole thoroughly mixed, until every particle of the aggregate is covered with a coating of the mortar.

The concrete is then ready to be put in place and should be used at once.

Platforms.—In using mixing boxes, a certain amount of

time or expense is lost in lifting the material over the side of the box. This has led in some cases to the substitution of a platform, upon which the mixing is done.

These mixing platforms have been used with success in cases where the concrete was to be used as a foundation for pavements or for the subway for cable roads, etc. The width of a platform should be such that a man standing at one side can work beyond the center with a shovel. The length depends upon the amount of concrete to be mixed at one time.

When the platforms are only 8 or 10 feet long they either may rest directly upon the ground or have wooden shoes under them, similar to those under a stone drag. When longer, they have been built with small, broad iron trucks.

The method of manipulation is as follows:

The platform is dragged into place. The concrete material has already been deposited at that point in approximately the correct proportions. A barrel of cement is placed on the platform and both ends knocked out. It is then ended from one end of the platform to the other and the cement dropping out each time the barrel is turned, is thus distributed over the platform. A number of empty barrels without heads are then placed upon one end of the platform and filled with sand and gravel. These barrels are ended from one end to the other and the aggregate thus distributed. This dry material is then turned rapidly with shovels, three times, then drawn to each side and the proper amount of water added. The water is usually in a barrel or tank mounted upon wheels. As soon as the water is added the whole mass is turned and mixed some three or four times and then shoveled at once into place. The platform is dragged ahead to the next point and the work goes on.

Machine Mixing.—When the amount of concrete to be mixed in one place becomes considerable, the mixing is usually done by machinery. There are a great number of these concrete mixing machines upon the market, but we will treat only of the different types, and not of the merits of the individual machine.

The type of machine to be used depends to a certain extent upon the character of concrete to be made. That is, whether it is to be made of coarse broken stone or finely broken stone and sand. One of the simplest forms of concrete mixer is that shown in Plate II. It consists of a cubical wooden or iron box, this box is fixed to a horizontal shaft, the shaft being fastened to two of the diagonally opposite corners. By means of gearing the shaft is rotated and with it the box. There is a proper opening in the box, that can be closed tightly. The concrete material, cement, sand, gravel or broken stone, and water, is placed in the box in the correct proportions and the opening closed. The box is revolved a number of times—usually about five—then stopped and the thoroughly mixed material is run out into a barrow, box, cart, or any other receptacle. The box being hung by the corners, the material is thrown from side to side and from end to end in each revolution. The mixing by means of this machine is best done when the aggregate has a maximum size of a hen's egg; when sand and finely ground aggregate, alone are used, the mixing is not as well done, as the material does not fall as freely from one side of the box to the other. Care

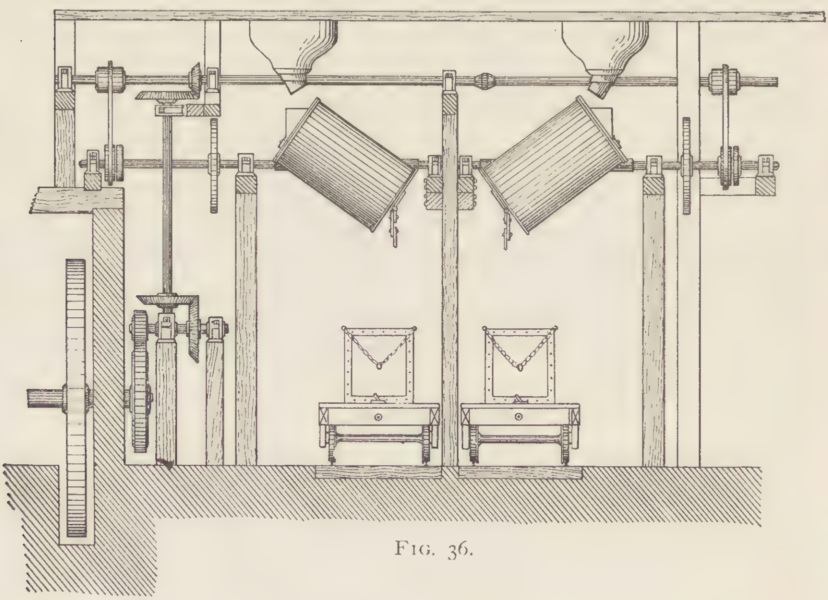

FIG. 36.

must be taken not to rotate the box too rapidly, but to allow sufficient time for the material to fall from one side to the other. Fig. 36 shows a more elaborate mixing machine upon this same principle.

In the type of machine just described, the different materials for making the concrete are all put in the tumbler box or cylinder and all mixed at once. There is a type of machine

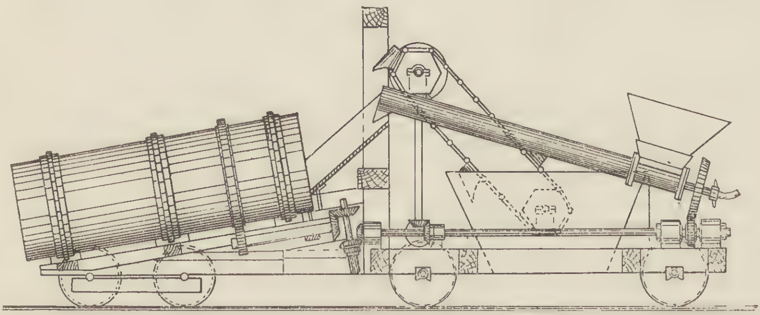

FIG. 37.

shown in Fig. 37, in which the sand, cement and water are thoroughly mixed and then the broken stone or gravel added. The sand, cement and water are put in the cement hopper. In the bottom of this hopper is a large endless screw that runs in the tube. The revolving of this screw thoroughly mixes the mortar and forces it out of the upper end of the tube into the chute, down which it runs into the mixing cylinder. The broken stone or gravel is placed in the box below the tube, carried up by means of the chain and bucket elevator, and thrown into the chute, from which it passes with the mortar into the mixing cylinder and comes out at the lower end thoroughly mixed. The capacity of this machine is about 65 cubic yards per day.

Machines similar to this are made that have two delivery chutes at the back for the discharge of the concrete. Such machines are used for the depositing of concrete in two parallel trenches, when it is used as a foundation for street railway tracks. In types of mixing machines, such as just described, the mixing is done by some form of a revolving

endless screw or revolving beaters and they can only be used with advantage when the aggregate is small.

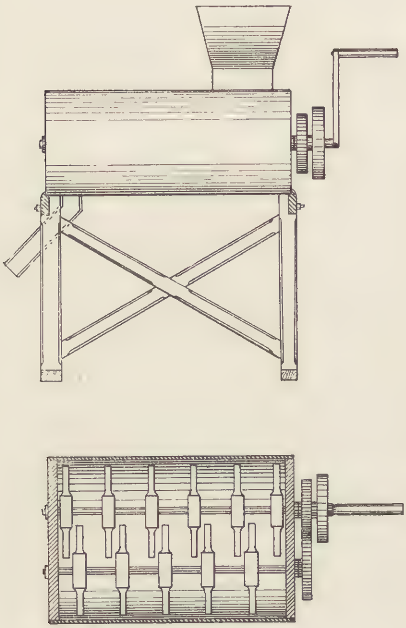

FIG. 38.

Fig. 38 shows a very simple form of mixing machine that may be run by hand. A small one of this type has been found very useful in laboratory experiments.

The quality of the cement used depends upon the required character of the concrete. For foundations for building, any first-class natural cement will answer the purpose.

For very important and expensive foundations, particularly those under water, the best Portland should be used. By the best Portland, is meant, not only a Portland that will comply with the test specifications, but a brand of cement that has been tested to such an extent that the engineer may have no doubt as to its *uniformity* of character. This quality of uniformity of production will do more to sell a cement than any other.

For foundations for pavments, the best natural cements answer the purpose.

For lining cisterns and reservoirs, some natural cements are suitable, and a good Portland with about 20 % lime makes a most excellent working mortar.

For all side-walk work, only the best Portland should be used. In any work where the concrete will be subjected to attrition or wear, only the best Portland should be used.

In the laying of cement walks, attempts have been made to use a base of natural cement concrete with a covering or wearing surface of Portland cement. So far this has not been

successful. The union between the two kinds of concrete has not been perfect and the result has been that, in a short time, the top was scaled off.

For the manufacture of artificial stone, only the best Portland should be used, unless some special patent cement, made for that purpose, is used.

There are a number of these patent processes in vogue, that appear to give good results. As the author has not experimented upon them, and is not familiar with their composition, he is unable to give any opinion as to their relative merits.

Only a few of the more general uses of cement have been mentioned and what has been said in regard to the use of natural or Portland cements must be taken in the form of suggestions rather than a statement of absolute facts.

Sand.—The sand should be clean and sharp.

Aggregates clean, angular and of graduated size up to the maximum. Hard and tough.

Proportions.—The proportions, in which the ingredients should be used, depend upon so many points, such as the quality of the constituents and requirements in the concrete, that they will not be taken up here. There are a number of specifications given, for various types of work that show what proportions are used.

Water.—The amount of water used is almost universally too great. The concrete when ready to be put in place should be merely a damp, incoherent mass.

There is very little danger of using too little water,

Mixing.—Under ordinary circumstances the sand and cement should be mixed dry, and then sufficient water added. The stone or gravel, having been thoroughly washed and wet should then be added and the whole mass worked and mixed.

Depositing Concrete.—Until within a comparatively few years there was much error existing as to the best methods of depositing concrete in place. For some unaccountable reason most of the older specifications specify that the concrete shall not be tamped after being put in place, and in order that it may be, to a certain extent, solidified, it was specified that it should

be dumped in place from a certain height. Nothing could have been more erroneous than such ideas. The concrete should not be allowed to fall a considerable height. Such a fall tends to separate the larger pieces from the smaller, and thus results in a lack of uniformity in the concrete. The concrete should be put in place with care, not allowed to fall more than 3 or 5 feet.

It should then be spread evenly and thoroughly tamped. The tamping should be done quickly, but should be done thoroughly. The concrete should not be laid in layers more than 6 or 8 inches in thickness. That is in layers not thicker than can be well tamped. Succeeding layers should be put in place before the previous ones have become set.

When the work is, from necessity, stopped for a length of time sufficient for the cement to become set, it should be left in the form of steps, and just before the next deposits of concrete are made, it is a good plan to cover the surface of the old concrete with a coating of thin grout, made of neat cement and an abundance of water, in order to make a perfect union between the deposits.

It is often specified that the tamping shall be continued until the water rises to the surface. If no more than the proper amount of water has been used, the tamping will have been sufficient long before any of this water will have appeared on the surface.

Depositing Concrete Under Water.—When concrete is to be deposited under water, some special device is necessary.

The concrete cannot be thrown into the water and allowed to sink by its own weight, for the reason that all the cement and mortar would thus be washed from the aggregate. Various devices are used.

The concrete is often placed in large paper sacks and lowered in place in this condition. The action of the water and the weight of the concrete, soon breaks the sacks and allows the concrete to unite.

Where the depth of water is not too great, a wooden tube or box can be used. The length of the box being greater

than the depth of water. The box is water tight, and the lower end fitted with a cover that can be opened from above. A certain amount of concrete is put into the lower end of the box and the box then lowered into the water until the lower end is near the place where the concrete is to be deposited. The cover is then opened and the concrete slides into place.

There are numerous devices in the shape of buckets that are used. The essential features of all of these buckets for

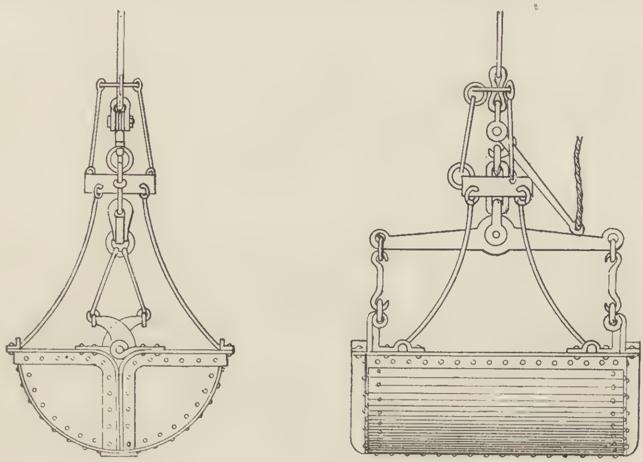

Fig. 39.

depositing concrete, are that the form should be such that when the bucket is opened, all of the contents may fall out and also that the device for opening shall be such that it can be worked from above. Fig. 39 shows one of these types used. Figs. 40 and 41 show a device for a heavy canvas bag open at both ends. The lower end is drawn together by a rope fastened in the manner shown in Fig. 41. The bag is filled with concrete and lowered into place. Then the sling rope is pulled, the sling comes off, the lower end opens and the concrete slides into place.

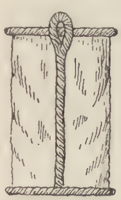

Fig. 40.

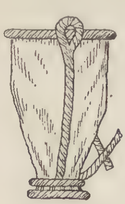

Fig. 41.

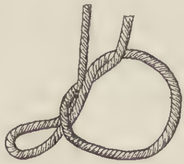

Fig. 42.

Pavements and Sidewalks.—The use of Portland cement for the paving of streets has never been general. But there are some few localities, such as in parts of London, where it has been used with great success, as far as the wearing qualities are concerned.

In order that concrete may serve as a pavement for general traffic, only the very best materials of every kind must be used and this necessity renders the cost so great as to be prohibitory excepting in rare instances. The manufacture of paving brick has reached such a degree of excellency and the product is sold at such a reasonable price that, probably, the day for cement pavement has passed.

In any of the Portland cement pavements in London the concrete was not made in place, but molded into blocks which after hardening were put in place as artificial stone blocks. As a foundation for a street pavement, concrete is used in enormous quantities. For this purpose the light-burned natural cements answer and thus the cost of the concrete is very much reduced.

The concrete for this purpose usually consists of the following proportions.

1	part	natural cement.
2 to 3	parts	sand, coarse and gravelly.
5 " 7	"	broken stone.

This cement concrete makes an ideal street covering when a suitable wearing surface is put over it. It presents a smooth, even surface and may be given any form or shape required. It is impervious to water and thus fulfills one of the most important requirements of street covering. The method of applying it is as follows:

The sub-grade is given the cross-section of the finished surface and rolled smooth and even.

The concrete is made and deposited in layers of the required thickness, usually from 6 to 9 inches, depending upon the nature of the sub-soil below and the character of the traffic above. The concrete is given the required contour by the use of a template. It is then thoroughly tamped, and the top

smoothed off. The concrete can be made at the sides of the streets and moved into place by barrows, or it can be made on platforms (see page 118) and put in place by shovels.

The concrete is usually allowed to set for three days, then a layer of sand from 1 to 2 inches in thickness is evenly spread over it, and the wearing surface, in the shape of granite blocks, bricks, or wooden blocks are put in place.

In order to obtain the best results with any given concrete, it is necessary that it should be kept damp and protected from the heat of the sun.

For this purpose the sand is usually thrown on a few hours after the concrete is in place, and the sand kept damp for several days.

Such a foundation as this, makes it a rather expensive matter to tear up the street for gas and water pipes, but with proper care the concrete can be replaced in a manner that in no way causes deterioration to the pavement.

Before a foundation such as this is laid on any street, the property owners should receive ample notification of the fact and also of what amount they may be fined, in addition to the actual cost of the repairs, in case they are the cause of the necessity of cutting the pavement.

Sidewalks.—For the purpose of constructing walks for foot travel alone, cement concrete has no superior.

Materials.—None but the best materials should be used. Portland cement, clean, sharp sand, and gravel or broken stone. If broken stone is used it should be broken somewhat finer than for macadam, as the walks are not made more than four inches deep. The walks are made of two classes of concrete, $3\frac{1}{2}$ inches of ordinary concrete consisting of cement, sand, gravel or broken stone. On top of this is a finishing coat of $\frac{1}{2}$ an inch or less, made of a rich cement mortar alone. Many attempts have been made to use the natural cement for the base and the expensive Portland cement for only the finishing coat.

Such experiments have as yet resulted in failure, the top coat invariably separating from the base and breaking off.

This is probably due to the fact that the Portland cement mortar was put upon the base before the base was set and the difference in the amount of contraction of the two concretes, while setting, prevented a union being formed. With our present knowledge of the making of cement walks, only the best Portland cement should be used throughout.

Foundation.—In localities subject to low temperatures much care should be given to the foundation below the concrete. The earth is excavated to a depth of 8 or 10 inches below the required surface of the walk and from 4 to 6 inches of sand or furnace cinders spread and well tamped.

Frames.—The necessary frames are usually made of 2×4 inch studding. Suppose the walk is to be 6 feet wide. On one side of the walk is set a piece of 2×4 on edge, the top being just the height of the finished walk. This is held in place by means of stakes driven on each side, those on the outside being much the stronger. Down the center of the walk is placed another frame, at such a distance from the outside frame that the clear distance between them is one-half the width of the walk. Two cross pieces are put in at such a distance apart that one batch of concrete will fill the intervening space. For framing around curves, thin ceiling stuff may be used, or sheet iron.

Mixing the Concrete.—The concrete is mixed by hand, and in the same manner as described on page 118. The work is done in two boxes, one large one for the heavy layer, and a smaller one for the top coating. The lower layer should be mixed with as little water as possible. The top coating has much more water, and should be of such a consistency as to work well under a trowel.

Manipulation.—The frames are filled with the coarse concrete until it comes up even with the top. It is smoothed off with a straight edge, resting on the two frames and moved back and forth. It is then tamped with small, flat, iron tampers, the tampers having a smooth face 4 inches square and a wooden handle. The concrete is compressed sufficiently by the tamping to give the right depth for the top

coating. After the tamping the surface is quickly smoothed off with a trowel. Before the top coating is put on this bottom coat is cut into blocks of any desired size, usually about 3 feet square. This cutting is done with a trowel, worked along a straight edge, the trowel being forced entirely through the concrete. The surface being smoothed off, the top coating is applied. This is spread quickly and evenly with a wooden float and brought flush with the top of the frames. It is struck perfectly true with a straight edge, and then troweled down smoothly. The troweler works with a smoothing trowel in each hand and puts considerable pressure upon them. After the top coat has been smoothed the character of the desired surface decides the next step. If a perfectly smooth surface is desired, some neat cement is sifted over the top, and the whole surface polished down. When a rougher surface is desired, the top is smoothed down and then some coarse *clean* sand sifted over it. The troweler goes lightly over the surface to partially imbed the sand. Another method is to indent the surface. A small brass roller is used, the surface of which is covered with pointed studs that, in passing, indent the surface. After the surface has been finished it is marked off in lines to correspond with the cuttings through the concrete. The marking is done by means of a chalk line stretched between the ends of the desired mark. This line is then pressed into the soft mortar with a small trowel, and being removed, leaves the mark. After the surface has been finished the walk is left to harden. For several days the surface should be kept wet. This is particularly necessary in dry, hot weather, in order to avoid the appearance of sun cracks. These so-called sun cracks are fine, hair-like cracks that may often be seen upon the surface of finished cement work. They do not in any way impair the durability of the work, and are due to the too quick drying of the surface.

As the work of laying the concrete advances, the small stakes on the inside of the frames are removed.

In a few days the frames are removed and are used over

and over again. When the other side of the walk is put in, the concrete already in place serves as a frame on that side.

Cement Curbing.—The frames for cement curbing should be made of two-inch plank dressed on one side. The width of the frame should equal the depth of the curbing. The planks are held together by cleats nailed on the rough side. These cleats should be from 3 to 4 inches wide and at one end of each section the cleat should project half its width beyond the ends of the plank. The ends of the plank should be cut off true and square, and when the sections are fitted together, the end of one section will come inside this projecting cleat and thus be held in line. The frames are held in place by means of heavy stakes driven on the outside and pieces of board sawed to the desired thickness of the curbing, on the inside, holding the frames apart.

The concrete for curbing is made of cement and sand, no gravel or broken stone being used, unless the curbing is of extraordinary thickness. This concrete is mixed about the consistency of damp sand, filled in between the frames and thoroughly tamped. The top is finished off with a trowel, if square, or to any desired cross-section by means of a template. The frames are not removed until the concrete has become thoroughly set. The back frame is removed first and the earth tamped back in place.

The number of men in a gang for making cement walks is four. One troweler and three helpers. One of these helpers assists on the frames and tamps the concrete. The other two mix the mortar and concrete.

Outfit.—Two tampers, 1 axe, 1 sledge hammer, 1 saw, 1 hand hammer, 2 hoes, 2 shovels, 2 wheelbarrows, 1 large mixing box 14 ft. long, 3 ft. wide and 1 ft. deep.

One small mortar box, 2 or 3 wooden buckets, 1 straight edge, 1 pointing trowel, 2 floats, 2 smoothing trowels, 1 chalk line, 1 sieve; gravel screen if necessary.

In straight work, when no time is lost setting the frames, one troweler should keep three helpers busy and should lay and finish 500 square feet per day.

For a gang of four men, the following amounts of material will make a convenient amount of concrete and mortar to handle and an amount that can be handled in such a time as to obviate any danger of an incipient set.

The proportions given are correct for thoroughly good cement walks and have been proved by the author.

Concrete Base.—One and one-half bbls. Portland cement, 1 cu. yd. river gravel and coarse sand.

Top Coating.—One-eighth cu. yd. sharp clean sand, $\frac{1}{2}$ bbl. Portland cement. This amount will make between 90 and 100 square feet of cement walk 4 inches thick.

Making in Molds.—Slabs for cement walks and curbing may be made in molds under cover and stored away for future use. They are then put in place and handled in the same manner as sandstone. When made in molds the slabs are not more than 2 feet square usually. Any desired color can be given to the work by mixing this color with the mortar.

Repairing Masonry.—Owing to the immense amount of masonry construction that has been done in this country during the last fifty years, there have been many instances where an inferior quality of building stone has been used in structures of considerable importance. In some cases the stone did not possess good "weathering" qualities and soon began to disintegrate. This type of masonry has been very frequently repaired by the use of Portland cement mortar. The exposed face of the masonry being covered with a coating of mortar, put on in the same manner as plaster.

The surface to be so repaired should be thoroughly cleaned, all dust, dirt and vegetable growth removed, and then thoroughly wet, before the mortar is applied.

For good work the mortar should be proportioned 1 part cement and not more than 3 parts clean, sharp sand. Sufficient water should be used to give it the consistency of lime-mortar used for plastering. It can be applied with a trowel and then worked down and smoothed.

Another method of applying the mortar is as follows: some of the details of the method have been patented.

The surface is cleaned and wet, all of the joints are thoroughly scraped out and all loose mortar or stones removed.

A shield of plank is put up at any distance from the masonry, so that the distance between it and the masonry shall be the thickness required for the cement coating. A water tight joint is made between the shield and the masonry to be repaired.

The cement mortar is made very thin by the excessive use of water. This form of mortar is called "Grout." This semi-liquid mass is then forced into the space back of the shield and into all the interstices of the masonry by means of a force pump.

In this manner, arches, piers, retaining walls, etc., have been repaired in a most satisfactory manner.*

Artificial Stone.—In the different uses of cement thus far spoken of, the concrete has been put in place and allowed to harden there. There is, however, another most important method of using concrete and that is molding it into blocks of any required shape allowing it to harden in the molds and then using it in the form of artificial stone, in the same manner as any other variety of stone. Artificial stone blocks of great size have been used in large quantities at different ports along the Mediterranean for the purpose of building break-waters and sea-walls. There was no good building stone obtainable within a reasonable distance and there were all the necessary constitutents for good concrete in abundance. Lime, sand and clay.

These blocks were usually what is known as "Coignet's Béton Aggloméré" and the ingredients were more or less, hydraulic lime and fine sand. The jetties of the Suez Canal are built of Béton Aggloméré composed of hydraulic lime of Theil and the exceedingly fine sand of the desert. The blocks weighed about 20 tons and were allowed to harden some two or three months in the air before they were immersed in the sea.

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*For a full description of this process, see Engineering News.

The result has been satisfactory although no engineer would take the chances of failure by using only hydraulic lime when by the addition of a little Portland cement the concrete would have been so vastly improved and all possible danger done away with. This Béton has been used in great quantities all over France for the building of sewers, aqueducts and buildings of all sorts and sizes.

In the manufacture of Béton, it will be noticed that no broken stone or gravel is used. Some type of cement or lime and sharp sand. In France at least its use has been attended with marked success. One of the largest works in which it has been used in monolithic form is the Vanne Aqueduct, that supplies Paris with water, 37 miles in length. There are 2 or 3 miles of arches, some of them are 50 feet high, 8 or 10 arch bridges 75 to 100 feet in span. The pipe, itself, is $6\frac{1}{2}$ feet interior diameter, 9 inches thick on top and 12 inches on the sides near the water level. It appears to be impermeable to water. Nearly 40 miles of sewers, in Paris have been built of the same material and have been satisfactory.

In this country, no monolithic sewers or aqueducts of cement concrete have been constructed, for the reason that iron, stoneware pipe and brick are better suited to the purpose at a much less cost. The locks on the Hennepin canal are monolithic structues of Portland cement concrete. The materials used are imported Portland cement, river gravel and sand, and broken stone. Plate I. shows the stone crushing plant. Plate II. shows the concrete mixing machine, which consists of a box hung at diagonal corners and capable of being revolved. Plates III. and IV. give different views of the locks, more or less completed. A good idea of the massive structure of the work can be obtained from these plates. Heavy timber frames are erected and the concrete filled in between, in layers and tamped. The whole mass is kept wet during the process of setting and in order to insure this for the interior of the mass vertical holes were left in the concrete and these were kept filled with water until such a time, that none of it was absorbed by the concrete.

Probably the most striking examples that we have of monolithic concrete structures are some of the large hotels in Florida and parts of California.

Plate V. is an exterior view of the Museum Building of the Leland Stanford Jr. University, and Plate VI. shows an interior view of the same. This is a monolithic concrete structure and was built by Ransom, Smith & Co., of San Francisco, California.

Plate VII. shows a small bridge built upon the University grounds and is a good example of what is possible in the direction of imitating ornamental stone work.

Portland cement concrete, if allowed a sufficient time to harden, is capable of offering great resistance to wear of any kind and has great durabilty in resisting the action of the elements. But a number of months, at least, are necessary before this great resisting power becomes developed. The fact that such a length of time is necessary before Portland cement concrete possesses the resisting power of good building stone, has been a very serious drawback to its general use as artificial stone for finer ornamental and architectural purposes, unless the artificial stone was carefully stored under cover for a considerable period of time the finer details would become effaced upon exposure. The better the ultimate quality of the concrete the slower it is in hardening, and consequently the longer time it must be stored before it can be used with safety. When used in comparatively large masses or in such a form as not to render fine delicate tracery necessary, the small amount of disintegration that takes place is of no importance. The facility and ease with which concrete may be molded into any required shape, makes it a most desirable material for many constructive purposes.

These two facts soon led to experiments being made to obviate this defect, and also to produce some solution that could be applied not only to artificial stone but also natural building stones that would render them impervious to water and to the action of vitiated atmospheres.

The application of a liquid glass has been found to be among the most beneficial.

An analysis of the compound used is about:

Silicic acid, ...	23.21
Soda, ...	8.90
Potash, ...	2.52
Water, ...	65.37
	100.00

This compound, when sufficiently diluted with water and applied to the surface of stone, either natural or artificial, forms a thin surface of glass over it, that presents a resistance to the elements, that would not be obtained by the concrete alone for many months and never by the natural stone.

The most successful application of this silicating process has been made in England in the manufature of paving blocks. The following description of which is taken from Henry Reid on the Manufacture and Use of Portland Cement, page 383.

Victoria Stone. Aggregate. The best granite, broken finely and carefully washed to remove dust and any clayey material. Only the very best Portland cement is used. This is a *sine qua non*. In the molding room the materials are mixed in varying proportions, to suit the future requirements of the blocks. The slabs are made with both sides alike, so that when one side becomes worn it may be turned over. After being molded the slabs are kept at least seven days before being dipped in the silica tanks. It is allowed to stay in the baths some ten days and then stored away for use.

Concrete made of the best materials and with the greatest care has considerable power of absorption, and it is this quality that is taken advantage of in this process.

*This silicating process would only be allowable in concrete made of Portland or some extremely hydraulic cement, for the reason that this double silicate of soda and potash which is formed completely excludes the air from any communication

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*See "A Practical Treatise on Natural and Artificial Concrete," by Henry Reid, page 154. There is quite a detailed article in this book upon artificial stone and the silicating process.

with the interior of the mass, and if the concrete were made of lime as a matrix the interior never would become hard.

There is another compound that in solution has been found to render masonry impervious to water, "Sylvester's Process for Repelling Moisture from External Walls." This process consists of the application of two washes to the exterior face of the masonry.

No. 1—	Castile soap, ...	$\frac{3}{4}$ lbs.
	Water, ...	1 gal.
No. 2—	Alum, ...	$\frac{1}{2}$ lb.
	Water, ...	4 gals.

Apply No. 1 as near the temperature of boiling as possible with a stiff brush and rub until the masonry is covered with a lather. Permit to dry 24 hours, and then apply solution No. 2. In 24 hours repeat this; and on ordinary brick masonry about three applications are usually sufficient.*

The properties of this solution have led to the patenting of the so-called *McMurtie Stone*. This stone is made of Portland cement concrete, in the pores of which are formed the compounds of alumina and the acids resulting from the double decomposition of alum and soap. These compounds are insoluble in water, and are not acted on by the carbonic acid in the air. The early strength of the stone is increased, and the ultimate strength not at all diminished.

Frear Stone.—Composed of clean, sharp sand and Portland cement, to which is added some gum shellac.

Proportions—

1 part cement.
$2\frac{1}{2}$ parts sand.
1 ounce shellac to 1 cubic foot of stone.

Rammed in molds and stored for some months. Used some in Chicago, but not always with satisfactory results.

Ransom Stone.—Crushed and washed granite, sand, or gravel.

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*See Baker's Masonry Construction, p. 178.

METHOD OF MANUFACTURE.

One gallon silicate of soda mixed with 1 bushel of sand or other aggregate, rammed into molds; immersed, under pressure, in hot solution of chloride of calcium; thoroughly washed in cold water. Result most excellent when good materials are used.

Sorel Stone.—Cement, oxychloride of magnesium; formed by adding solution of chloride of magnesium to the oxide of magnesium. The proper strengths and proportions being used a cement of great hydraulic energy is the result.

Used with properly powdered stone of good quality, it makes the hardest and strongest artificial stone yet produced, and is in every way equal to the natural stone that furnishes the powder. It is used principally for emery wheels, imitation marble, soapstone stoves, etc.

ESTIMATES OF QUANTITIES.

Lime.—One barrel unslaked lime weighs about 230 pounds. One barrel unslaked lime will make about $2\frac{1}{4}$ barrels of stiff lime paste, equal to 0.3 cu. yd.

One barrel of lime paste and three barrels of sand will make three barrels of mortar, equal to 0.4 cu. yd. One barrel of unslaked lime will make 6.75 barrels of good 1 to 3 mortar, equal to 0.95 cu. yd.

Cement.—Portland weighs 400 pounds per barrel gross and about 375 pounds net.

Rosendale 300 pounds net per barrel.

Milwaukee and Utica about 260 pounds net.

Portland as packed will measure about 1.2 barrels loose.

Rosendale about 1.25 to 1.40.

Milwaukee and Utica about 1.1.

One cubic foot dry cement shaken down but not pressed will make about 0.63 cu. ft. stiff paste, when mixed with 25 to 30% of water.

One barrel of Rosendale will make about 3.75 cu. ft. stiff paste, or about 80 pounds Rosendale will make one cu. ft. stiff paste.

Volume for volume Portland will make about the same amount of paste as the naturals That is 100 pounds of Portland will make one cu. foot of paste.

In mixing mortar in large quantities the units of measurement are usually a packed barrel of cement and a loose barrel of sand.

CEMENT AND SAND REQUIRED FOR ONE CUBIC YARD OF MORTAR.

	PROPORTION OF SAND TO CEMENT.						
	0	1	2	3	4	5	6
Portland in barrels,	7.14	4.16	2.85	2.00	1.70	1.25	1.18
Utica, ...	6.42	3.73	2.57	1.80	1.53	1.13	1.06
Sand cu. yds., . .	0	0.67	0.84	0.94	0.98	0.99	1.00

The cement is given in barrels packed, the sand in cubic yards.

AMOUNT OF MORTAR REQUIRED FOR A CUBIC YARD OF MASONRY.

DESCRIPTION OF MASONRY.	VOL. OF MORTAR CU. YDS.	
	MIN.	MAX.
Concrete; broken stone; no gravel in screenings	0.50	0.55
Rough rubble	0.33	0.40
Rough jointed rubble	0.25	0.30
Squared stone masonry	0.15	0.20
Ashlar 12″–20″ courses $\frac{3}{8}$″ to $\frac{1}{2}$″ joints	0.07	0.08
" 20″–30″ " $\frac{1}{4}$″ to $\frac{3}{8}$″ "	0.05	0.06
" largest blocks and courses	0.03	0.04
Brickwork; $\frac{5}{8}$″ to $\frac{1}{2}$″ joints	0.35	0.40
" $\frac{3}{8}$″ to $\frac{1}{4}$″ "	0.25	0.30
" $\frac{1}{8}$″ " *	0.10	0.15

Trautwine's Engineer's Pocket Book, p. 679:

For 1 cu. yd. of concrete of broken stone and sand, without voids, 1 cu. yd. broken stone with 0.5 bulk voids, requiring 0.5 cu. yds. of sand and 0.25 cu. yds. of cement. Abstracted from Gillmore on Limes, Cements, etc., p. 321.

*Up to this point this *data* for estimates is taken from Baker's Masonry Construction, p. 87, by permission of the author.

CONCRETE NO. 1.

1 bbl. German Portland cement, } 5.4 bbls. concrete mortar.
5½ bbls. loose sand,

6 bbls. gravel, } 12½ bbls. mixed and shaken down, containing 26½ % voids.
9 bbls. broken stone,

The above makes 50 cu. ft. of rammed cement.

CONCRETE NO. 2.

1 bbl. German Portland cement, } 5.7 bbls. concrete mortar.
6 bbls. damp, loose sand,

5 bbls. gravel, } contains 30 % voids.
9 bbls. broken stone,

The above makes 50 cu. ft. rammed concrete.

CONCRETE NO. 3.

1 bbl. French Portland cement,
1 bbl. slaked, ground lime powder, } 7 bbls. mortar.
7 bbls. loose sand,

13 bbls. gravel, } 22¾ bbls. mixed together and shaken down with 24 % voids.
13 bbls. broken stone,

The above makes 86¼ cu. ft. of rammed concrete. The strength is good, crushing at the end of two months at 300 pounds per square inch.

CONCRETE NO. 5.

1 bbl. French Portland cement,
1¼ bbls. slaked, ground lime, } 7.9 bbls. of concrete mortar.
8 bbls. loose sand,

16 bbls. gravel, } 28 bbls. mixed together and shaken down with 24 % of voids.
16 bbls. broken stone,

One batch of the above makes 105 cu. ft. rammed concrete, suitable for ordinary uses.

CONCRETE NO. 5.

1 bbl. Rosendale cement, 3 bbls. damp, loose sand, 5 bbls. broken stone,	3.27 bbls. of concrete mortar.

The above makes 21.75 cu. ft. of rammed concrete.

CONCRETE NO. 6.

1 bbl. Portland cement, 1 bbl. *unslaked* lime, 10 bbls. loose sand, 16 bbls. broken stone,	10.37 bbls. of concrete mortar.

The above makes $69\frac{1}{2}$ cu. ft. of concrete rammed in place.

Plate I. Stone Crushing Plant, Hennepin Canal.

Plate II. Concrete Mixer, Hennepin Canal.

Plate III. Hennepin Canal. Completed Walls of Lock No. 37.

24 ft. high, 11 ft. base, 4 ft. coping.

Plate IV. Hennepin Canal. Interior of Lock No. 37, with Masonry Complete.

PLATE V. MUSEUM BUILDING, LELAND STANFORD JR. UNIVERSITY, PALO ALTO, CALIFORNIA.

MONOLITHIC CONSTRUCTION, UNDER RANSOM'S CONCRETE AND TWISTED IRON PATENTS.

RANSOM, SMITH & CO., 101 SANSOME ST., SAN FRANCISCO, CAL.

PLATE VI. INTERIOR OF MUSEUM BUILDING, LELAND STANFORD JR. UNIVERSITY, PALO ALTO, CALIFORNIA.

MONOLITHIC CONSTRUCTION UNDER RANSOM'S CONCRETE AND TWISTED IRON PATENTS.

RANSOM, SMITH & CO., 101 SANSOME ST., SAN FRANCISCO, CAL.

PLATE VII. BRIDGE ON GROUNDS OF LELAND STANFORD JR. UNIVERSITY, PALO ALTO, CALIFORNIA.

MONOLITHIC CONSTRUCTION UNDER RANSOM'S CONCRETE AND TWISTED IRON PATENTS.

RANSOM, SMITH & CO., 101 SANSOME ST., SAN FRANCISCO, CAL.

CHAPTER IX.

CEMENT TESTS.

ENGINEERING DEPARTMENT, STATE UNIVERSITY OF IOWA.

THE Cement Tests, of which this chapter is a report, were made in the Cement Laboratories of the Engineering Department of the State University of Iowa, Iowa City.

The entire work was done by various engineering students and under the personal supervision and direction of the author. The different tests are here numbered, merely for convenience. The numbers indicate nothing however as to the order in which the work was done. The results of each test were written by the different students and what follows are abstracts from these various reports:

CEMENT TEST NO. 1.

The tests were made by E. W. Crellen, J. H. Howe, and Hubert Remley, class of '90. Mr. Remley completed the tests and wrote the report. (See The Transit, Vol. I., No. 2.)

The points studied in these tests were as follows:

(*a*) The difference in strength of briquettes of the same age and same cement, due to being allowed to harden in dry air and to hardening under water.

(*b*) The rate of increase in strength in the different cements due to time, under the two above mentioned conditions.

(*c*) The actual breaking strength per square inch of the various cements tested at different ages.

(*d*) The differences that exist in the behavior of the light-burned natural cements and the Portland cements.

Temperature.—The temperature of the laboratory was between 60° and 70° Fah. and the temperature of the water was from 5° to 10° lower.

Immersion Tanks.—The tanks were so arranged that the water was constantly changing.

Briquettes.—The size and shape of the briquette was the same as that shown in Fig. 10, page 45.

Molds.—For hand made briquettes the molds used were similar to those shown in Fig. 11, page 46.

Briquette Machine.—The Jameson Briquette Machine was used, Figs. 17, 18, 19, 20; pp. 49–52.

Testing Machine.—The testing machine, used for breaking the briquettes was Reihle Bros. 1,000 pound cement tester, Fig. 27, page 99.

Making Briquettes.—When the briquettes were to be made by hand, the cement and water were mixed upon a large glass slab. When the briquette machine was to be used, the mixing was done in a small iron sink.

Cement.—All of the cement tested was furnished, free of cost, by the makers. The makers were informed that the cement was to be used for a series of laboratory tests.

Treatment of Briquettes.—All briquettes after being made were placed upon some non-absorbent surface, such as glass, and covered with a wet cloth. At the end of twenty-four hours the cloth was removed and a portion of the briquettes were immersed and the remainder, allowed to harden in the air.

Age of Briquettes.—The age of the briquettes given in the following tables, and shown in the diagrams, dates from the time of the removal of the wet cloth, or twenty-four hours after the briquettes were made.

Breaking Briquettes.—Those briquettes that hardened under water were taken from the water and immediately broken.

The clips, on the testing machine were, as those shown in Fig. 23, page 53, with rubber buffers.

Sand.—All sand used was a sharp, white, flint-glass sand from near Aurora, Ill. The size used was what passed through a No. 20 sieve and was caught on a No. 30 sieve.

PERCENTAGE OF FINENESS OF CEMENT.*

The percentage of fineness should be found for each cement

*What follows is taken directly from Mr. Remley's report.—The Transit Vol. I., No. 2.

since the degree of fineness to which it is ground, affects the strength to a considerable extent. A quantity of the cement is carefully weighed, and sifted through a sieve having 2,500 meshes to the square inch. It must be carefully shaken until no more will pass through, and this can be shown by sifting over white paper. The residue is then weighed and the percentage of fineness is found for this cement with this sieve. What passes is then sifted through a sieve having 10,000 meshes to the square inch, the same care being taken as before, to pass all that will pass. The amount remaining in the sieve is then weighed and the weight added to the weight of the residue remaining in the coarser sieve and subtracted from the weight of the whole. This *should* give the weight of what passes both sieves, but some of the cement is lost in the process, passing off into the air in the shape of dust, so that the residue only which is heavy and coarse, and not liable to be blown away, should be taken into account in determining the percentage of fineness, the total amount being divided into the difference of the whole and residue remaining. The sieves used in these experiments were of Riehle's manufacture.

RESULTS OF EXPERIMENTS WITH CONCLUSIONS.

The following gives the brands and corresponding numbers used:

TABLE I.

No.	Brand	Class.	Address.
No. 1.	Milwaukee	Natural.	Milwaukee, Wis.
No. 2.	K. B. & S............	Portland.	London Eng.
No. 3.	Louisville	Natural.	Louisville, Ky.
No. 4.	Empire (Lond'n Brand)	Portland.	Warners, N. Y.
No. 5.	Gibb's (Diam'd Brand)	Portland.	Gray's Essex, Eng.
No. 6.	Rosendale	Natural.	New York State.
No. 7.	F. O. Norton....... ...	Natural.	New York State.
No. 8.	Burnham's............	Portland.	London, Eng.
No. 9.	Fewer's................	Portland.	Germany.
No. 10.	Buckeye...............	Portland.	Bellefontaine, O.
No. 11.	Josson & Co..........	Portland.	Antwerp, Belgium.
No. 13.	Millen's Patent.......	Portland.	Warners, N. Y.
No. 14.	Utica Black Ball.......	Natural.	La Salle, Ill.
No. 15.	Hoffman's Rosendale..	Natural.	Kingston, N. Y.
No. 16.	South Bend Cement Co.	Portland.	South Bend, Ind.
No. 17.	Empire	Portland.	Warners, N. Y.

WATER HARDENED BRIQUETTES.

Table 2 gives the results obtained by the breaking of about 2,200 hand made briquettes after the expiration of six months time. Excluding those of No. 10, of which only a few were broken, each of the figures is the average strain withstood by about 24 water hardened specimens.

TABLE II.

Number of Cement.	Unsifted Cement.					Sifted Cement.				
	Neat.	1 part sand.	2 parts sand.	3 parts sand.	4 parts sand,	Neat.	1 part sand.	2 parts sand.	3 parts sand.	4 parts sand.
No. 1.	333	222	186	158	134	316	229	207	177	155
No. 2.	623	443	279	189	180	553	474	342	272	206
No. 3.	325	253	156	143	101	256	228	165	150	96
No. 4.	518	335	276	214	163	450	420	336	269	242
No. 5.	609	442	296	238	175	539	476	360	281	228
No. 6.	362	237	178	132	121	334	256	204	152	131
No. 7.	350	265	221	166	145	316	259	218	189	151
No. 8.	576	373	273	204	165	518	455	344	250	210
No. 9.	553	447	363	285	230	559	529	394	313	235
No. 10.	669					628	409	240	215	130

As before stated, all proportions of sand and cement were taken by weight. This will account for the difference of these results from those usually obtained. The advantage of this method of proportioning is that the proportion can be more exactly made, but since in practice all is done by volume, it may be better to discard this method.

A series of rough experiments show that the average weight of a cubic centimeter of artificial cement dry and pressed down was 136 milligrams, while that of natural cement was only 114 under the same conditions, and that of sand was 156. The ratio of weight to weight is 6 to 5, or in equal weights of both cements the volumes would be in the ratio of $\frac{1}{6}$ to $\frac{1}{5}$.

Taking the weights of unit volumes of natural and artificial cements and sand as 114, 136 and 156 respectively, as given above, the following table was computed, showing the per cent. of volume of cement in briquettes of different proportions of sand and cement:

TABLE III.

CLASS.	NEAT.	1 PART SAND.	2 PARTS SAND.	3 PARTS SAND.	4 PARTS SAND.	5 PARTS SAND.
Natural	100	57.7	40.6	31.5	25.5	21.4
Portland	100	53.4	36.4	27.6	22.3	

It will be readily seen from this table that in briquettes of the same proportion of sand and cement, by weight, that there is more of the natural cement by volume than there is of the Portland cement.

The apparently small difference between the breaking strain of four part sand briquettes of Portland and natural cements will be explained by the difference in weight, as compared with the volume of the two cements. Table III. shows that in a five part sand natural cement briquette there is very nearly the same amount of cement by volume as in a four part sand Portland cement briquette, so that in order to compare the relative strength for the same volume of cement we must compare either the neat of the Portland with that of the natural, or the four parts sand Portland with the five parts sand natural.

Since the different cements of the same class are of different weight, the same difficulty is involved, and the only exact comparison can be made with the neat cement. It is also on account of the difference of weight that the strength of a heavier cement appears to decrease more rapidly with the addition of sand. For example, the strain withstood by 4^{4n} is 163, while that withstood by 7^{4n} is 145, but of No. 4 there is only 23 per cent. by volume, while of No. 7 there is 26 per cent. of cement in the briquettes.

Table II. gives higher breaking strains than are usually given, and this is accounted for by Table III., where it will be seen that the proportion of cement by volume in a briquette proportioned by weight is greater than in one proportioned by volume. Thus, in a four part sand natural cement briquette, the percentage by weight of cement is 20, while by volume it is 25.5, or it must be compared with a three part sand briquette in other tables where the volume is the basis of

proportioning. As a general rule, the strength of natural cement, when used with four parts sand, can be compared with Portland cement with three parts sand by weight, the difference by volume being slight.

Taking all things into consideration, together with the fact that the test is not made on a given weight, but on a given volume, it would appear better to take the proportions of sand and cement by volume.

According to the Trautwine, the average cost of Portland cement is $2.63 per barrel of about 400 pounds gross, or 380 pounds net, or 7 cents per pound, while that of the natural cement is $1.21 per barrel of 300 pounds net, or 4 cents per pound.

Table IV. gives the average breaking strains of the natural and Portland cements, No. 10 excepted, taken from Table II.

TABLE IV.

Class.	Unsifted.					Sifted.				
	Neat.	1 part sand.	2parts sand.	3parts sand.	4parts sand.	Neat.	1 part sand.	2parts sand.	3parts sand.	4parts sand.
Natural.........	342	244	185	150	125	305	243	199	167	144
Portland........	576	408	297	226	183	524	471	355	277	224

The natural cement being only 83.8 per cent. as heavy as the Portland, the comparative cost of a given bulk of the two is in the ratio of .7 to .838 x .4 or .7 to .335.

In order to attain the same strength with a natural cement as with a Portland, it is necessary to use a larger amount. Now the question is whether the same strength can be attained for the same cost. The amount that may be economically spent for natural cement to arrive at the same total strength may be found by comparing the strength and cost of unit volumes. In the case of neat unsifted cement the following proportion is had: 567 : .7 : : 342 : x, or the strength of the Portland is to the cost as the strength of the natural is to the amount that could be economically spent, or x equals .415, while the actual comparative cost is .335. From this it appears that it would be justifiable to spend 23.9 per cent.

more than it actually costs, or .4956 cents per pound to get the same total strength as from the Portland. In the following table the first column shows the proportions of sand and unsifted cement; the second, the amount actually spent for a unit volume of the natural; the third, the comparative amount that can be economically spent to arrive at the same strength as with Portland; the fourth, the percentage of increase over the cost, and the fifth, the number of cents per pound allowable to spend.

TABLE VI.

1	2	3	4	5
Neat.	·335	·415	23.9	.496
1 part sand.	·335	·389	16.1	.464
2 parts sand.	·335	·391	16.7	.467
3 parts sand.	·335	·407	21.5	.486
4 parts sand.	·335	·418	24.2	·497

From this it would appear that when the proportion of sand and cement is one to one, that either the comparative cost of Portland is the least or that of the natural is the most, but from other tables it will be seen that the latter is the case.

Table VII. shows the strain a given bulk of cement will stand when united with different proportions of sand by weight. It was compiled from Tables II. and III., by dividing the strain actually withstood, in Table II., by the percentage of cement in Table III., for corresponding groups of specimens.

TABLE VII.

Class.	Unsifted.					Sifted.				
	Neat.	1 part sand.	2parts sand.	3parts sand.	4parts sand.	Neat.	1 part sand.	2parts sand.	3parts sand.	4parts sand.
Natural	342	423	456	476	490	305	422	490	530	565
Portland	576	764	816	819	820	524	881	975	1004	1005
Per cent. of strength of natural to Portland	59.2	55.3	55.9	58.1	59.7	58.2	47.9	50.2	52.8	56.2

This table shows that after the addition of one part sand

the rate of total increase of strength is comparatively small, being less in the Portland than in the natural. The percentage of breaking strain of the natural as compared with the Portland is least when the proportion of sand and cement is one to one, continually increasing both in the case of the sifted and the unsifted with the addition of sand until with four parts sand it is nearly the same as with the neat cements. The rate of increase of both the natural and Portland cement continually decreases with the addition of sand, arriving, in the case of the Portland, at nearly the minimum when the proportion of sand and cement is two to one with the unsifted cement, and three to one with the sifted. In both the unsifted and the sifted the strength of the Portland increases more rapidly at first with the addition of sand than the natural, while at about the proportion of four to one of sand and cement the percentage of strength of natural to Portland is almost equal to that of the neat cements.

The total strength of a given bulk of cement, as indicated in the table is greater with the sifted cement upon the addition of sand because of the larger amount of active material in the cement, the residue caught on the sieves being perfectly inert and acting as so much sand. The fact that a portion of the unsifted cement is inert, does not, however, explain the fact that the percentage of strength of natural to Portland when sifted, is less than when unsifted. Table VII. also shows that, taking the sifted neat as composed almost wholly of active particles, that the strength at first increases rapidly with the amount of sand or inactive material added, overcoming the tendency to an increased strength due to a larger amount of active material, up to and even above the point where the grit is from zero to 25 per cent. of the active material, or in other words, that the unsifted cement having a percentage of fineness of from zero to 25 and consequently less active material, is stronger than the same bulk of sifted cement with zero to 25 per cent. more active material. The fact that the natural cement contains, on an average, 2.5 per cent more grit, explains its higher percentage of strength as compared with

the Portland in the unsifted specimens, because, taking the sifted cement as active, and since the strength increases with the amount of grit within limits more rapidly than with the amount of active material added, the strength of the former increases more than that of the latter from one to two per cent.

In using sand and cement, it is necessary to have the cement finely ground in order that each individual grain of sand may be covered with a layer of cement to cause a firm bond of union. Fine grinding produces a lighter cement, reduces the percentage of fineness, increases the amount of active material for a given weight, and allows a more perfect intermixing of sand and cement. Experiments go to show that as a rule, the heavier the cement, the degree of fineness being the same, the stronger it is, so that either the degree of fineness and the weight per bushel, the weight per bushel and the strength, or the degree of fineness and the strength may be specified, and the cement filling the specifications will be satisfactory in most cases. Buyers should insist on fine grinding as more active material is purchased for the money and with this, insist on a strength with neat sifted cement. The results show that the strength of specimens of neat cement of the same brand diminishes with the percentage of fineness.

PERCENTAGE OF FINENESS.

Number.	50 Sieve.	100 Sieve.
No. 1	95.75	87.65
No. 2	95.1	84.5
No. 3	84.6	77.4
No. 4	89.9	77.2
No. 5	90.5	81.8
No. 6	86.55	78.3
No. 7	92.95	87.1
No. 8	91.55	78.8
No. 9	98.71	93.2
No. 10	99.25	95.7
No. 13	98.4	88.6
No. 14	87.	77.3
No. 15	93.4	84.3
No. 16	95.15	85.85

Examination of Table II. shows that the strength, as a rule, decreases in the following order: n, s, ls, ln, 2s, 2n, 3s, 3n, 4s, 4n; and all conclusions drawn from those following Table II.

will apply to Table II. and to the individual results. Individual specimens show great variations in strength and cannot be trusted to give good results when taken alone, but rather the mean of many specimens must be taken.

An examination of the books showing the breaking strains of the individual specimens shows that many do not break in the minimum section, and that, as a general rule, those that broke in a larger section withstood a strain greater in proportion to the increase of section. Some cements make a point of breaking in other than the minimum section. At sight it might be supposed that on account of this fact the strain recorded was too great, but rather the strain recorded is too small, because the specimen did not break at the smallest, and hence the weakest, portion, but at a larger section because of the pressure of the clips. Nearly 25 per cent. break along a line connecting the points of contact of the clips, some cements being more apt to break here than others. As an example, out of 148 machine made briquettes of No. 11 103 broke along this line, while of 120 of No. 16 only 28 broke in other than the minimum section, or 70 per cent. of No. 11 to less than 22 per cent. of No. 16. Both were neat, unsifted Portland cements.

Diagrams.—The results of the tests are shown in the diagrams. There is a separate diagram for each brand of cement tested, the breaking strain of the briquettes hardened in air as in the original, being indicated by a dotted curve. The marked dots also belong to the dry cement. The brand, number, place of manufacture, class and percentage of fineness is also indicated on the diagram. The breaking strains of some of the individual specimens are indicated also. That of specimens hardened in water are shown by open circles of a larger diameter than of the black "average dots." The breaking strains of the air hardened specimens are shown by the circles with a cross within them. Only the individual specimens showing a greater strain than the average are thus indicated, and, of course, a circle, which in some cases appears as a dot, when below a line, does not belong to that line. The

dots occur only at 1 week, 4 weeks, near 13 and 26 weeks and nowhere else, and this will help to distinguish dots and circles. The circles are of slightly larger diameter also. The greatest difficulty is with the diagrams of Nos. 6 and 15. The large black dots averaging about 75 pounds above the dotted line in No. 6 are supposed to be crossed circles. All in No. 15 should be crossed. One diagram, as marked, shows the average breaking strain of the Portland and natural cements tested, hardened in water. A good idea of the effect of time on the different brands of cement will be obtained from the careful study of the diagrams. Perhaps the first thing that strikes the observer is the irregularity of the curves, but a general curve can be easily traced, the cut balancing the fill, thus giving a regular curve. Since specimens broken on the same day vary greatly, and since the increase of strength due to one week's time is not a great deal, irregularity is to be expected, but as is seen in the diagram showing the average of all of each class, the irregularity is done away with largely, because of the greater number of specimens entering into the averages.

These experiments are of especial value in showing the effect of time as well as the strength.

TABLE IX.

	No. 1.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 10.	No. 11.	No. 13.	No. 14.	No. 16.	Average Port.	Average Nat.	Per Cent. of Increase Port.	Per Cent. of Increase Nat.
1 week.	84	82	260	362	134	102	410	459	516	398	111	307	387	103		
1 week to 1 mo.	41	33	130	102	27	68	76	148	126	114	120	135	119	57	30.7	55.3
1 week to 3 mo.	174	78	251	274	251	285	249	354	192	282	237	221	261	204	67.2	189.
1 week to 6 mo.	262	282	353	341	305	339		386	265	371	245		355	252	91.7	244.6
1 mo. to 3 mo.	133	45	121	172	224	217	173	206	66	168	117	86	142	147	28.1	91.9
1 mo. to 6 mo.	221	249	223	239	278	271		238	139	257	125		236	195	46.6	121.9
3 mo. to 6 mo.	88	204	102	67	54	54		32	73	89	8		94	48	14.5	15.6

The gain in pounds in any cement from any one of the four dates to any other may be seen. The "average" columns were taken from the averages of the strains of natural and Portland cements and the per cent. columns give the percentage of the increase of strength between the times indicated, being calcu-

lated by combining the absolute strength with the increase of strength indicated in the "average" columns. The first line gives the actual breaking strain in pounds at the expiration of one week. From this it is seen that the natural cements, Nos. 1 and 3, are considerably below the average at this age, and that below three months, the increase is less, but from three to six months, the increase is more rapid than that of the average, being very apparent in the case of No. 3. Nos. 6, 7, and 14 are above the average, and the curves lie very near together. Of the Portland cements, No. 11 is noticeable on account of the rapidity with which it attains its strength, reaching 516 pounds in seven days. Of course, the increase after this spurt is less than that of the average. No. 10 appears to increase but little after three months, but attains a high strength before that time, the strength being way above the average. No. 13 with an initial strength at the end of the first week a little above the average increases at a rate considerably above it. Nos. 4, 5, and 16 are below the average, both in the point of initial and increase of strength. It will be noticed that all the natural cements and all of the Portland show nearly the same increase of strength, the Portland increasing more rapidly than the natural. The actual difference between the strength of Portland and natural is at the end of—

One week, . . .	284 pounds.
One month, . . .	346 "
Three months, . .	341 "
Six months, . . .	387 "
Average, . . .	337 "

After one month the increase of strength is very nearly the same for the average of both natural and Portland, and for the individual brands entering into the averages, so that a month test would give a very nearly correct idea of the comparative strength of the different brands up to six months. Thus when a set of specimens is broken after one month, the breaking strain for three and six months may be very approximately

determined by adding the mean of the increase of average strength given, or 145 pounds and 215 pounds respectively to the breaking strain at one month. The table showing the per cent. of increase is apt to give the impression that the natural increases more rapidly than the Portland, but when it is remembered that the absolute strength of the natural at six months is about one-half that of the Portland, it will be readily seen that although the per cent. of increase is greater the actual increase is not. All experiments carried on elsewhere go to show that the Portland increases in strength after six months and more rapidly than the natural.

The percentage of strength of natural to Portland is at—

TABLE X.

One week, ...	26.6 %
One month, ...	31.6 %
Three months, ...	47.4 %
Six months, ...	47.3 %
Hand made, six months, .	59.3 %

Air Hardened Briquettes.—The dotted broken line on the diagrams shows the increase of strength with time in the same manner as the full line shows the strength of the "wet" specimens.

Perhaps the first thing that engages the attention is the irregularity of the breaking strains. Some cements attain a certain strength in a very short time and weaken with age, while others act more in the manner of the water hardened specimens. The dry briquettes harden more rapidly than the wet ones, but ultimately attain much less strength. Natural cement briquettes, hardened in air, reach a greater strength than those hardened in water, and usually hold it for about three months, but after that time the latter is the stronger.

For the first three or four days after the immersion of the briquettes the Portland cement hardened in air seems to hold the supremacy in the point of strength, but it soon loses it.

Table XII. gives the average breaking strains of the natural and Portland cements of the groups of five and ten mentioned in the scheme, at—

TABLE XII.

Time.	Natural.		Portland.	
	In air.	In water.	In air.	In water.
1 week.	166	103	313	387
1 month.	275	160	448	506
3 months.	330	307	463	648
6 months.	314	355	536	742

From this table it will be seen that the natural cement hardened in air seems to lose its strength after three months. The drop in strength from 340 to 314 is partially due to the fact that at the age of three months No. 3 (Diagram No. 3) possessed an abnormal strength, but since there was no fault to find with the specimens broken, the results obtained from their breaking could not be thrown out just because of their strength. The diagram of No. 3 will also show the actual difference between the breaking strains of these five and of those composing the curve. But the fault does not lie wholly in No. 3, for Nos. 14 and 15 of the natural cements also lose a strength once attained. Although the average strength of the Portland cement increases with age, Portland cements Nos. 4, 5, and 13 lose strength with age. The following table corresponds to Table IX. for the water hardened specimens, and shows the increase of strength of specimens hardened in air from—

TABLE XIII.

Time.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 13.	No. 14.	No. 15.	No. 16.	No. 17.	Average Port.	Average Nat.	Per Cent. of increase Port.	Per Cent. of increase Nat.
1 week.	120	209	265	120	204	384	280	164	223	381	358	313	166		
1 week to 1 month.	123	177	269	90	116	24	221	24	200	11	93	135	109	43.1	65.7
1 week to 3 months.	353	81	171	135	126	182	140	194	43	221		150	170	47.9	102.4
1 week to 6 months.	97	340	243	241	161	208	216	151				223	148	71.2	89.1
1 month to 3 months.	230	96	98	45	10	158	81	170	157	210		15	61	3.3	22.2
1 month to 6 months.	26	163	26	151	45	184	5	127				88	39	19.6	14.2
3 months to 6 months.	256	259	72	100	35	26	76	43				73	22	15.8	6.5

The percentage of increase for both natural and Portland is greater for the period, one week to one month, in the air

hardened specimens than in the water hardened, the percentage of increase of the water hardened being considerably more after one month. The greater part of the ultimate strength of the air hardened cement is gained during the first month, although the Portland cement does gain about 20 per cent. more strength during the following five months. The actual difference between the strength of natural and Portland cements hardened in air is at—

One week,	147
One month,	173
Three months,	127
Six months,	222
Average,	167

Since the average difference between the strength of natural and Portland cements hardened in air is only 167 pounds while that between those hardened in water is 337 pounds, it is seen that Portland cement has not the qualities for hardening in air that makes it so valuable as a water hardening cement, the strength of the natural cement hardened in air and water being very nearly the same. The percentage of strength of natural to Portland is at—

TABLE XIV.

One week,	53. %
One month,	61.4 %
Three months,	72.6 %
Six months,	58.6 %

These percentages compared with those in Table X. also show that the difference of strength between the natural and Portland cements is less in the air hardened for the first three months, being nearly the same at six months.

As in the specimens hardened in water, the month's test may be considered as given a fairly good comparative test, but since the breaking strains of the individual specimens as well as those of the average are so irregular, tests of air hardened cements are not of much practical value. The

range of the breaking strains of specimens of the same cement broken on the same day is very often over 300 pounds. The following table gives the percentage of water, temperature of the mixing room, and the remarks on the setting as taken from the headings in the record book.

TABLE XV.

No.	Brand.	Pr. ct. of Water.	Temp.	Remarks.
No. 1	Milwaukee..........	31.8	70°	
No. 3	Louisville...........	26.8	62°	
No. 4	Empire (London)....	25.4	63°	
No. 5	Gibb's Portland......	21.4	65°	
No. 6	Rosendale...........	25	69°	
No. 7	F. O. Norton's.......	30	67°	
No. 8	Burham's Portland ..	22.5	70°	Quick setting for Portland Cement.
No. 10	Buckeye	26.25	68°	
No. 11	Josson & Co.'s Port..	23.125	73°	
No. 13	Millen's Patent......	21.5	65°	
No. 14	Utica Black Ball.....	33.75	69°	
No. 15	Hoffman's Rosendale.	32.5	67°	
No. 16	South Bend Cem. Co.	27.45	63°	Tem. rises slightly on addition of water. Quick setting for Portland.
No. 17	Empire	30	79°	Tem. rises slightly on addition of water.

The time required for setting varies with the cement, the Portland as a rule, requiring more time. A good cement should not heat on the addition of water nor should it swell in the least.

The amount of water used was such that when the pressure was applied, no water was forced out of the machine, but still large enough to moisten perfectly every particle of cement. The advantage of recording the percentage of water is that when mixing another batch, it is only neccessary to observe what percentage was used before to get the proper amount.

The temperature of the tank and mixing room was very nearly constant, ranging only from 62° in mid winter to 79° in the hottest part of July. The temperature of the water was about eight degrees below that of the rooms.

The natural cements may have almost any color from the very light straw colored Utica through the brown Louisville, to chocolate Rosendale. The Portland cements are usually a grayish blue or green, but never chocolate colored.

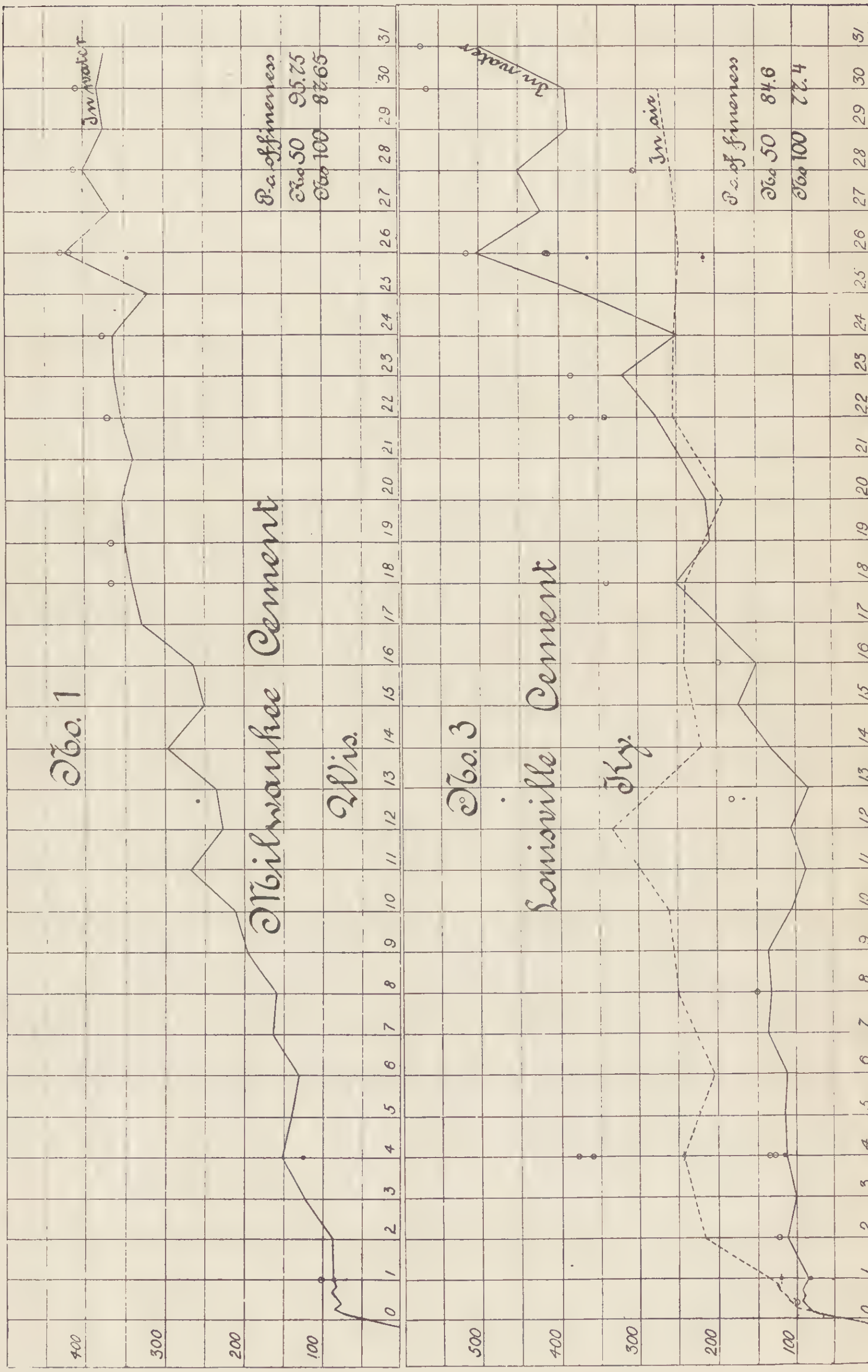
The following gives the strength of both hand and machine made briquettes of neat unsifted cement each broken at the age of six months:

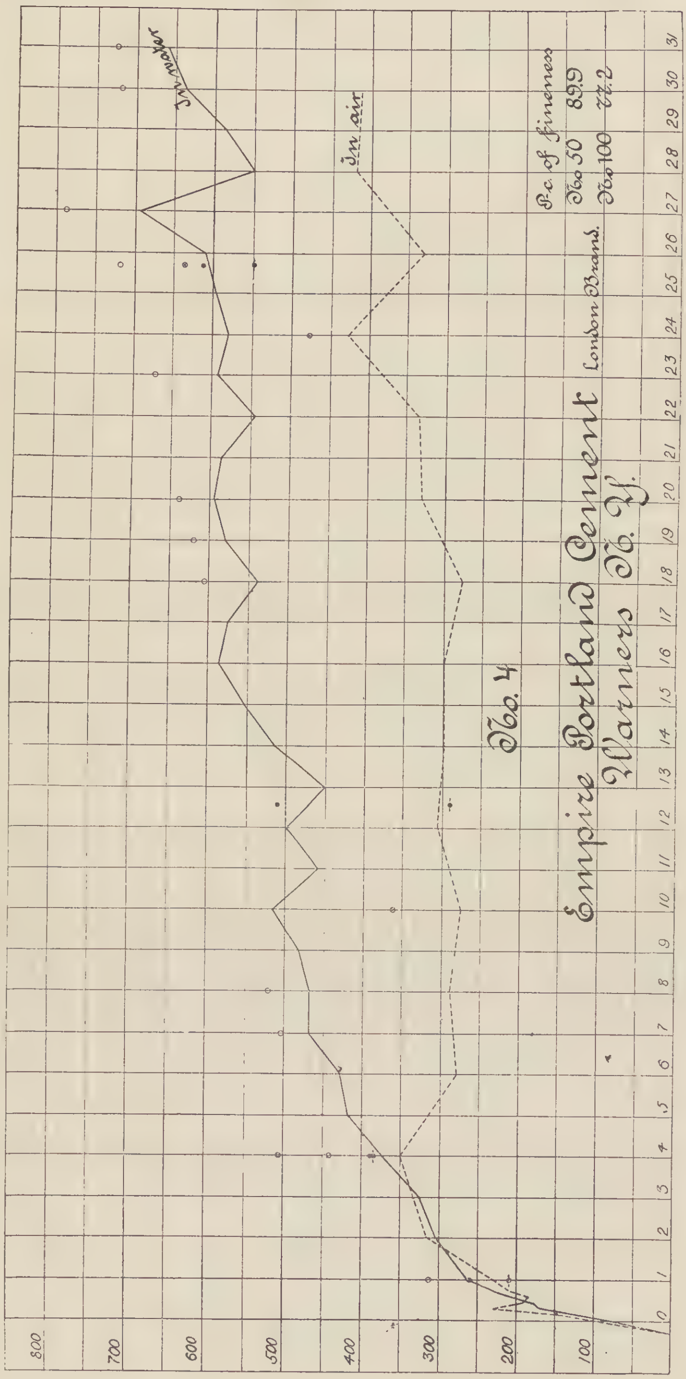
Cement.	Hand Made.	Machine.
No. 1	333	346
No. 3	325	364
No. 4	518	613
No. 5	609	703
No. 6	362	439
No. 7	350	441

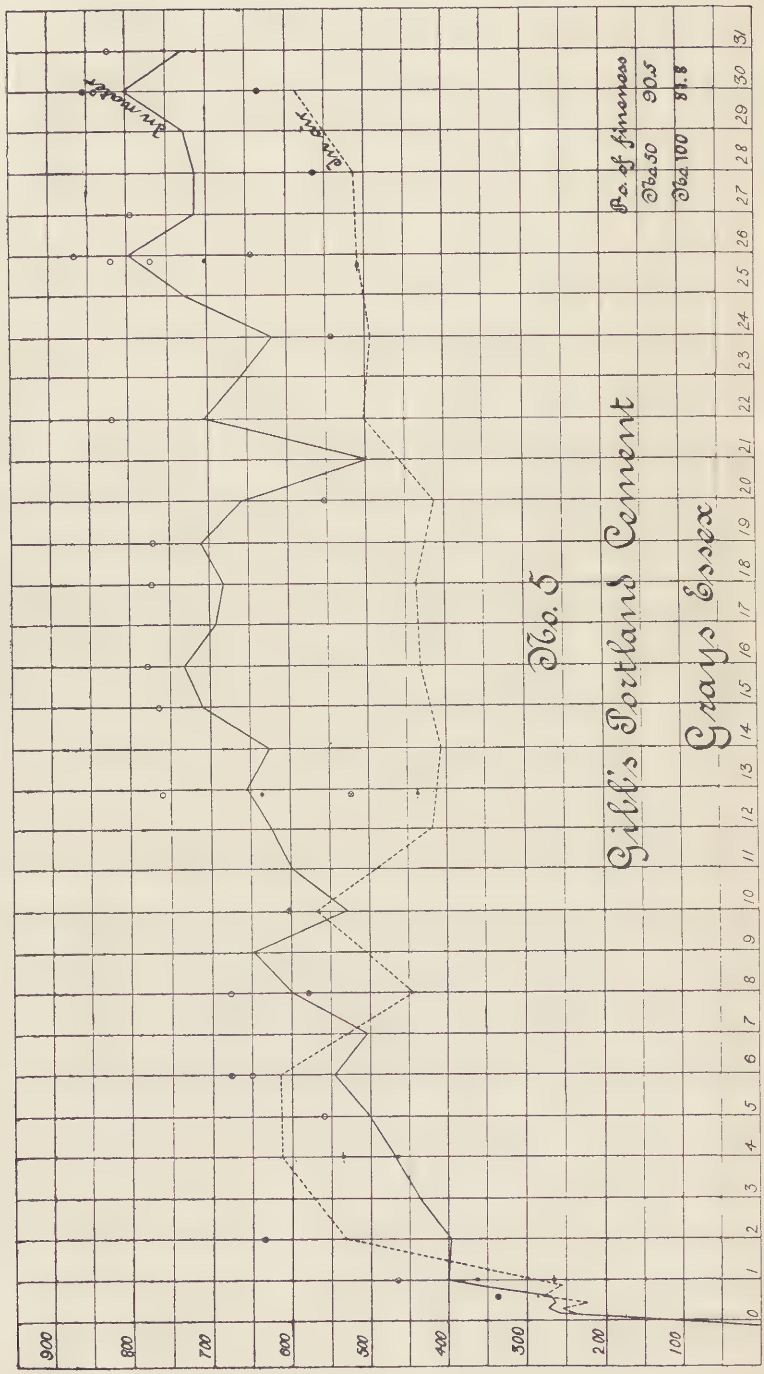
The above are only numbers that were tested in both cases at this age.

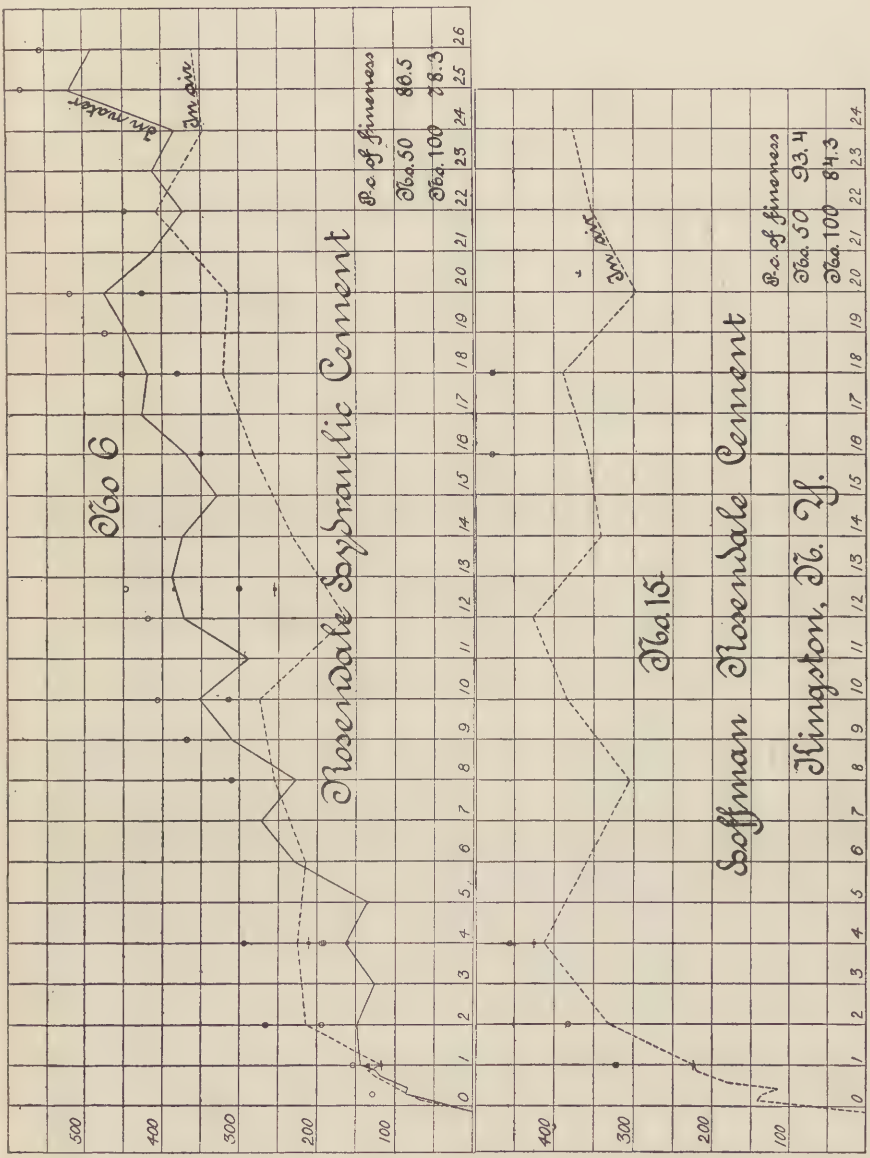
It will be noticed that the machine made briquettes stand a greater strain than the hand made. This is due, among other things, to the increase of pressure in forcing the cement in the molds, and to the small amount of water used in the construction of machine made briquettes. It might be reasoned that because of the greater strength of machine made briquettes that the comparative test is not a fair one because the strength of the Portland cement is increased more than that of the natural. This, however, is a false deduction. The percentage of increase is nearly the same on an average. One reason that the difference in strength between machine and hand made briquettes of Portland cement is greater than that of the natural cements may be due to the fact that the natural cement, setting more rapidly, did not receive all the patting that the Portland cement did—a temptation that the students found it impossible to resist. The Portland cement was removed from the mold before the initial set was as perfect as was the case with the natural cements, and experiments carried on at the Lake Tunnel Office in Chicago, show that the length of time the briquette is allowed to stand in the mold affects the breaking strain, increasing with the degree of initial set before removing. Machine made briquettes being forced into the mold under considerable pressure are removed immediately, which it is impossible to do with hand made. and none of the setting takes place in the mold, and all are treated alike.

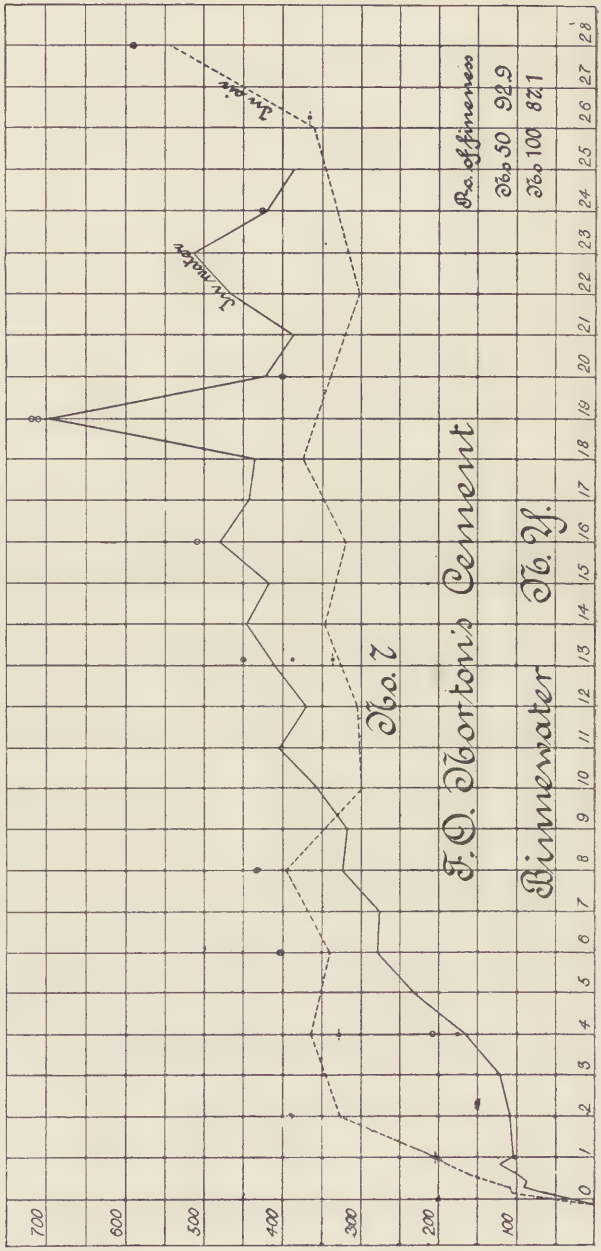
Hubert Remley, '90.

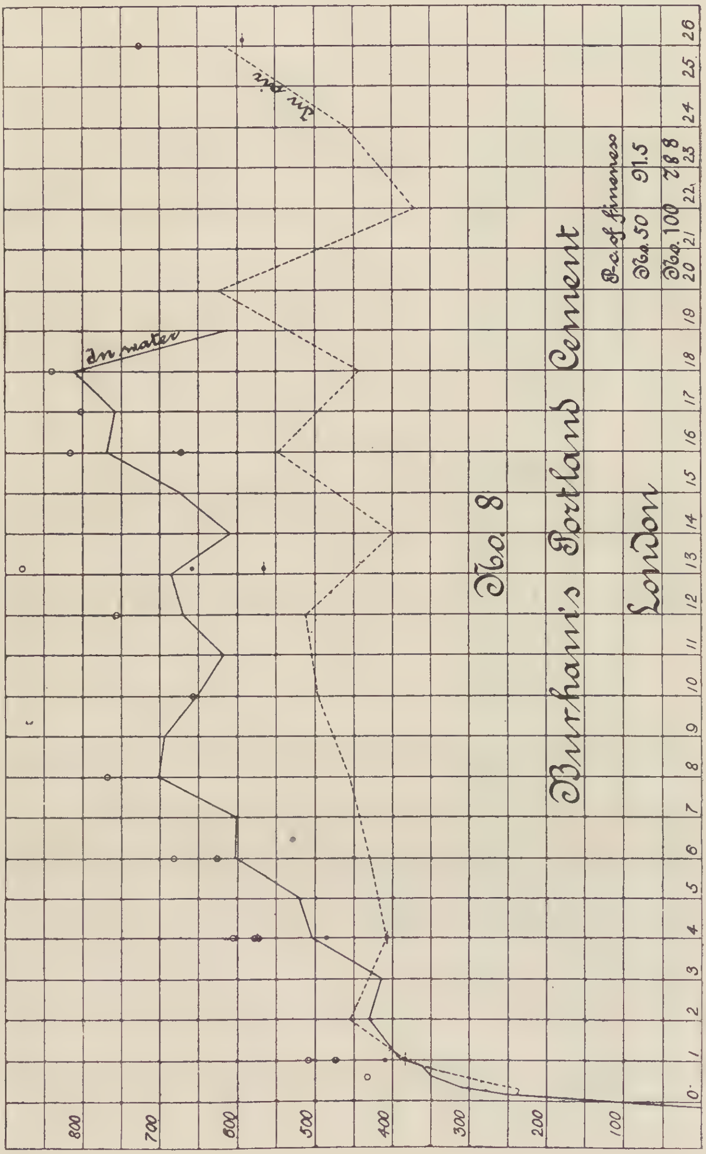

No. 1
Milwaukee Cement
Wis.
In water
P.c. of fineness
No. 50 95.75
No. 100 87.65
No. 3
Louisville Cement
Ky.
In water
In air
P.c. of fineness
No. 50 84.6
No. 100 77.4


In water
In air
P.c. of fineness
No. 50 89.9
No. 100 77.2
London Brand.
No. 4
Empire Portland Cement
Warners N. Y.
800
700
600
500
400
300
200
100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31


No. 5
Gill's Portland Cement
Grays Essex
Per. of fineness
No. 50 90.5
No. 100 81.8
In water
In air
900
800
700
600
500
400
300
200
100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31


No 6
Rosendale Hydraulic Cement
P.c of fineness
No. 50 86.5
No. 100 78.3
In water
In air
No. 15
Hoffman Rosendale Cement
Kingston, N. Y.
P.c. of fineness
No. 50 93.4
No. 100 84.3
In air
500
400
300
200
100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26


F. O. Norton's Cement
Binnewater N. Y.
No. 7
In air
In water
No. of fineness
No. 50 92.9
No. 100 87.1
700
600
500
400
300
200
100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28


No. 8
Burham's Portland Cement
London
P.c. of fineness
No. 50 91.5
No. 100 78.8
In water
In air
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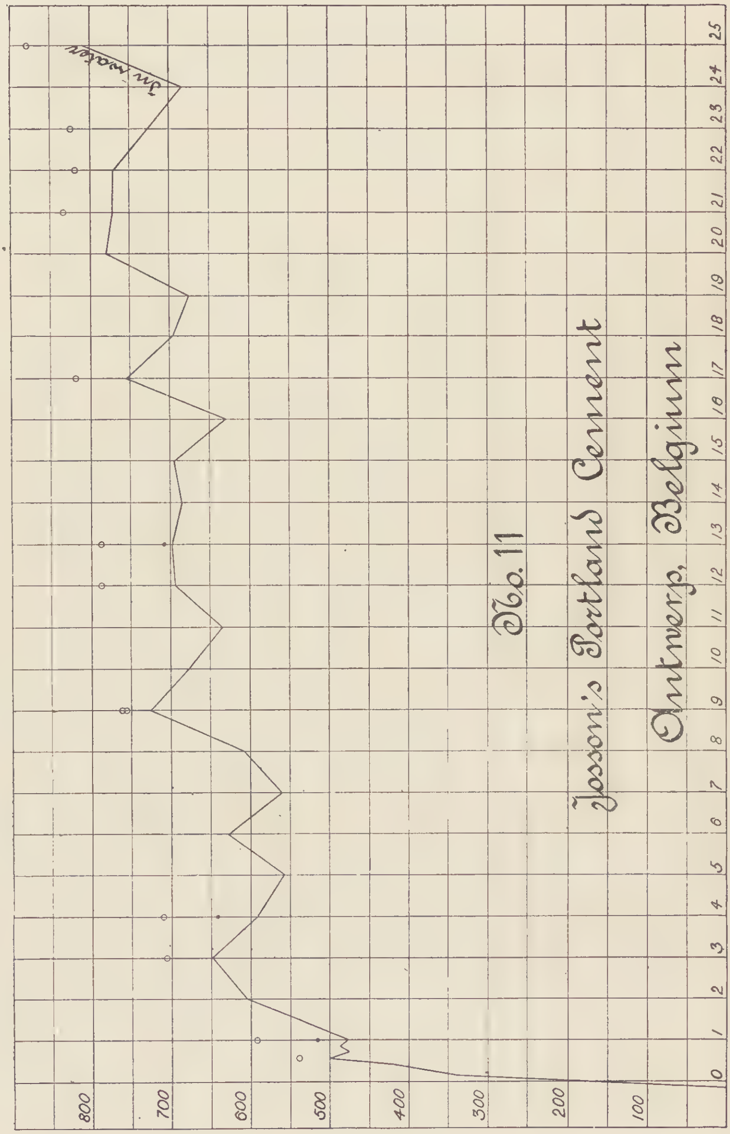
700
600
500
400
300
200
100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26


No. 11
Josson's Portland Cement
Antwerp, Belgium
In water
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700
600
500
400
300
200
100
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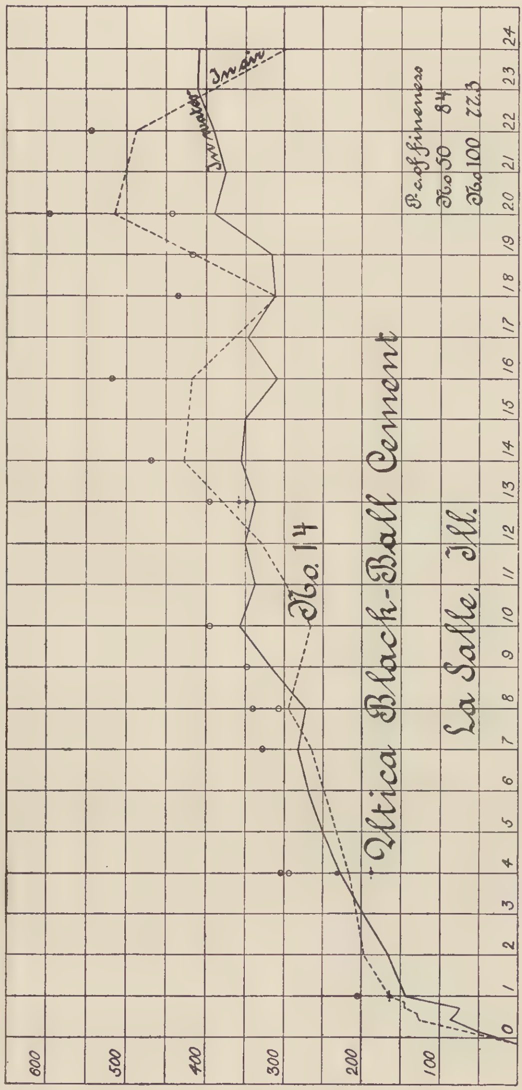
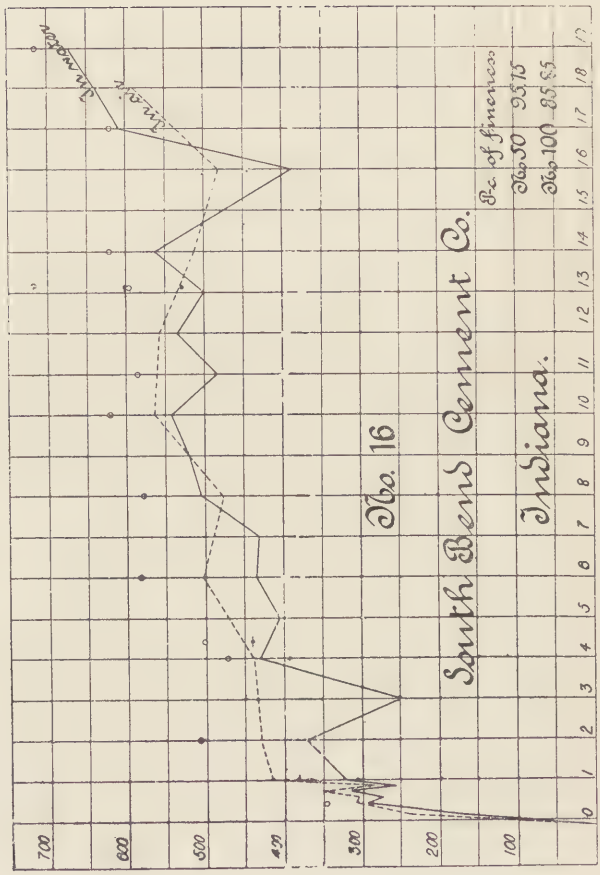
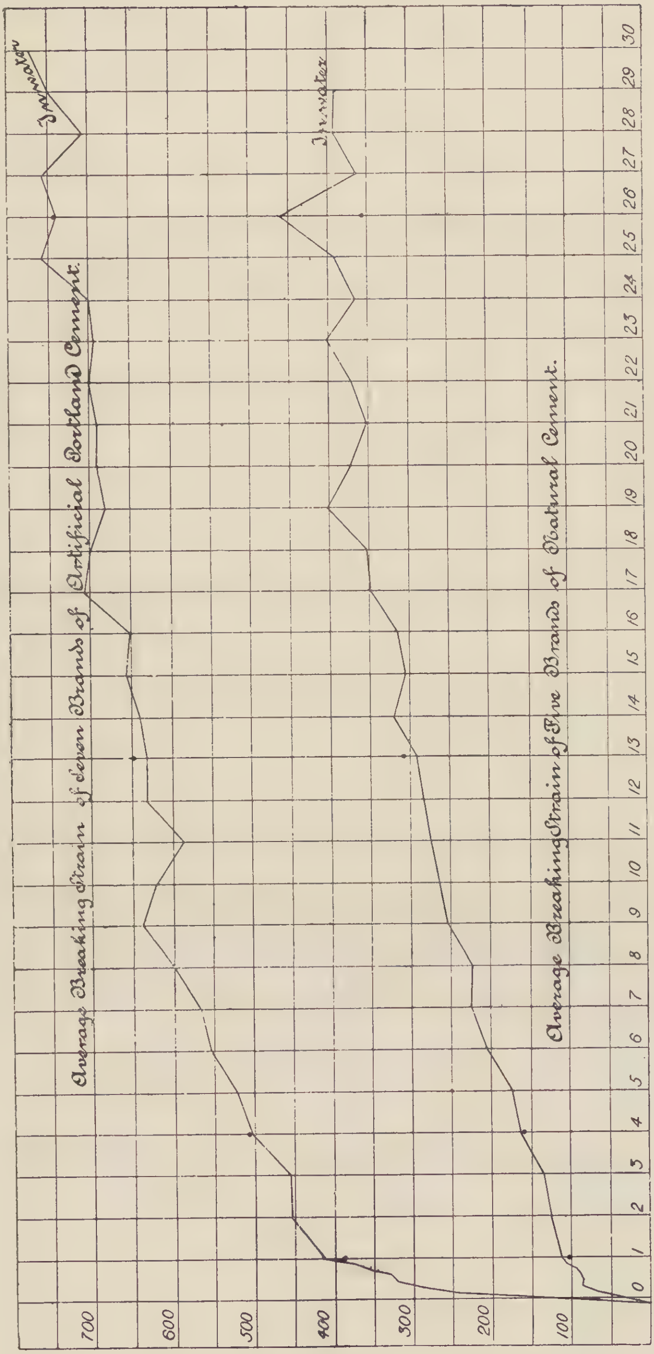
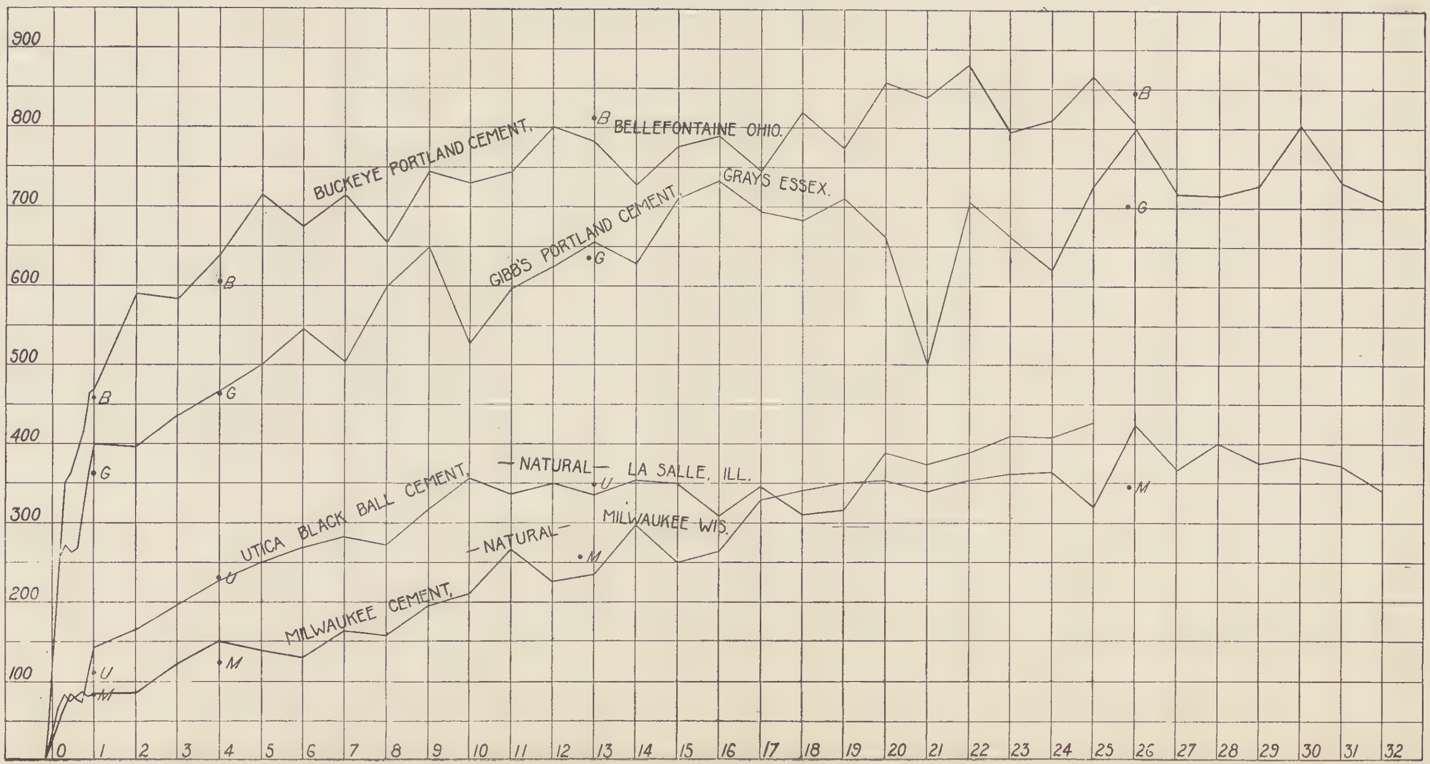

Utica Black-Ball Cement
La Salle, Ill.
No. 14
In water
In air
P.c. of fineness
No. 50 84
No. 100 77.3
600
500
400
300
200
100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24


No. 16
South Bend Cement Co.
Indiana.
P.c. of fineness
No. 50 95.15
No. 100 85.85
700
600
500
400
300
200
100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18


Average Breaking Strain of Seven Brands of Artificial Portland Cement.
Average Breaking Strain of Five Brands of Natural Cement.
In water
In water
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
100
200
300
400
500
600
700


BUCKEYE PORTLAND CEMENT, B BELLEFONTAINE OHIO.
GIBB'S PORTLAND CEMENT, GRAYS ESSEX.
UTICA BLACK BALL CEMENT, —NATURAL— LA SALLE, ILL.
MILWAUKEE CEMENT, —NATURAL— MILWAUKEE WIS.
900
800
700
600
500
400
300
200
100
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32

No. 2.

Abstract from the Graduating Thesis of M. I. Powers, '91, Engineering Department, State University of Iowa.

FRESH AND SALT WATER IN CEMENT MORTAR.

The variance in the results of recent experiments and the conclusions and results announced in text-books and earlier engineering papers as regards the relative effect of fresh and salt water upon the strength of cement mortar led the writer to make tests upon the subject the subject of a thesis. The tests were begun in February, and were limited to thirteen weeks. Since acquiring the results and making the diagrams it would be a source of much satisfaction to be able to continue the tests longer, which is impossible, however, all of the allotted time having been fully taken up.

In the following tests, seven brands of cement were used (see following tables), three of which were Portland and four natural cements. Five hundred briquettes were made of each different brand of cement as follows: two hundred with fresh water, two hundred with salt water (3 per cent. salt), and one hundred with 10 per cent. solution of salt water. Fifteen briquettes of each kind were broken at the interval of every week from the time they were made for a period of thirteen weeks, excepting those made with a 10 per cent. solution, which lasted but seven weeks. In making the briquettes, the cement was first carefully weighed in small batches, from fifteen to twenty pounds, depending upon the rapidity with which the cement set, and placed in a large galvanized iron mixing basin. The water was also carefully weighed and added, the minimum amount being used that would thoroughly mix the cement. The exact percentage of water used may be seen in the following tables. The cement was thoroughly mixed by hand. Experiments were made looking toward a machine mixer, but none were found to give as good satisfaction as hand mixing. Experiments with a pug machine, on the same principle as that described by Mr. A. Bent Russell, C. E., in the Engineering News of January 3, 1891,

and used by the St. Louis waterworks extension with alleged good results, showed the cement to be rolled up in small balls or lumps after shaking.

Satisfactory results may be obtained with a small quantity of cement, sufficient for one briquette, but where the briquettes are machine made, and a considerable quantity of cement required at each mixing, the results are not as good as could be desired. After mixing, the cement was molded into briquettes by the machine designed last year by Professor Jameson for that purpose, and described in The Transit, Number 2, and the Engineering News of February 7, 1891. This machine gives a pressure of 150 to 175 pounds per square inch, which aids in reducing the amount of water to a minimum. When made, the briquettes were placed in a galvanized iron pan, and covered with a damp cloth for twenty-four hours, and at the end of this time immersed in water in similar pans; those made with fresh water immersed in fresh water, and those made with 3 and 10 per cent. solutions of salt water immersed in 3 and 10 per cent. solutions respectively. The temperature of the laboratory and tank rooms was kept at a constant temperature from 60° to 65°.

The average breaking strain of the fifteen briquettes broken each week was taken as the breaking strain of that cement, for that week, and the tables and diagrams made from these strains. They were tested with a Riehle Bros. standard cement testing machine, with the addition of rubber buffer clips, which gave the breakage of fully 90 per cent. of the briquettes at the minimum section.

TABLE NO. I.

No.	Brand.	Kind.	Per. Ct. Water.	No. Briq. per lb.	Address.
1.	Utica Black Ball.......	Natural.	22.3	3.4	La Salle, Ill.
2.	Gibbs' Portland........	Portland.	15.6	3.8	Grays Essex Eng.
3.	Milwaukee	Natural.	20.8	4.8	Milwaukee, Wis
4.	Buckeye Portland......	Portland.	16.6	3.6	Bellefontaine, O.
5.	Utica J. Clark..........	Natural.	24.1	4.9	Utica, N. Y.
6.	Hoffman Rosendale....	Natural.	20.0	4.1	Kingston, N. Y.
7.	South Bend Cement....	Portland.	19.2	3.7	South Bend, Ind.

Table No. I. shows the name and character of the cement, the percentage of water used in mixing, the number of briquettes made to each pound of cement, and the addresses of the several cement firms. The diagrams show the average breaking results for each week, for each kind of cement with fresh and salt water solutions, and from these it will be seen that salt water increases the strength of cements considerably at first, but does not seem to continue the strength, at least not with the same percentage of increase as at first, as the cement mortar grows older. By looking at the diagrams, it will be noticed that the line representing the averages of salt water breakages, drops below the fresh water line in some of the cements during the last two or three weeks. Here it would be interesting to continue the tests further in order to see if this drop is a permanent one, or whether it is due simply to some irregularity in the cement, which latter is rather improbable. One significant fact is obtained from the tables and diagrams, namely, that the considerable percentage of increase in strength shown at first by the use of salt water does not continue the same with increasing age.

Briquettes mixed with a 10 per cent. solution of salt water were stronger in every case at first with the natural cements than those made with a 3 per cent. solution, while the Portland cements, with one exception, were weaker. From this and the diagrams showing the averages of Portland and natural cements with salt and fresh water, it will be seen that the effect of salt water upon Portland and natural cements is noticeably different.

In the Engineering News, of December 20th, 1890, is a statement of tests which were made by Mr. John Gartland, at Governor's Island, New York Harbor. These tests were made for the purpose of comparing the relative strengths of cement mortar when mixed with fresh and with salt water. From the results of his tests the conclusion is stated that the permanent gain in strength in Rosendale cements due to the use of salt water was about 20 per cent., and in the case of Portland cement not less than 10 per cent. permanent gain;

2,531 briquettes were broken and fifteen different brands of cement were used. In the tests which form the subject of this paper, seven different brands of cement were used and 3,500 briquettes broken, thus giving a much larger number of tests for averages than were used in the New York Harbor tests. In the former tests, the gain at first in both natural and Portland cements, taking the averages of the several brands of both, was about 30 per cent., but in the third month in both and in the second month with the natural cements, the gain becomes a minus quantity and the cements become weaker than those mixed with fresh water. Here too, the results, as shown by table III., are sufficiently uniform to show that the variation can scarcely be credited to irregularities in the cements in testing.

There can be no doubt that cement mixed with sea water gains considerably in strength during the first few weeks, but that it does not hold out, is clearly proved by these results from the Cement Testing Laboratories of the University.

TABLE NO. III.

	Natural Cements.			Portland Cements.		
Weeks.	Average Fresh Water Tests.	Average Salt Water 3 Per Cent.	Per cent. Average Gain in Strength of Salt over Fresh.	Average Fresh Water Tests.	Average of Salt Water 3 Per Cent.	Per. cent. Average Gain in Strength of Salt over Fresh.
1	86.7	103.9	20	331.9	406.7	22
2	104.0	135.4	30	350.4	506.7	33
3	118.5	152.7	28	376.7	509.0	35
4	143.0	133.1	7	403.1	550.9	36
5	154.5	170.1	10	492.4	531.7	8
6	180.2	195.3	8	443.5	487.9	10
7	199.7	189.2	5	508.0	515.0	1
8	200.9	207.3	3	513.0	564.6	10
9	221.8	213.4	3	532.9	540.0	1
10	233.5	216.7	8	624.1	543.6	3
11	262.7	247.9	2	568.2	584.3	3
12	271.2	247.8	9	582.3	355 3	5
13	279.5	260.3	7	578.1	542.6	6

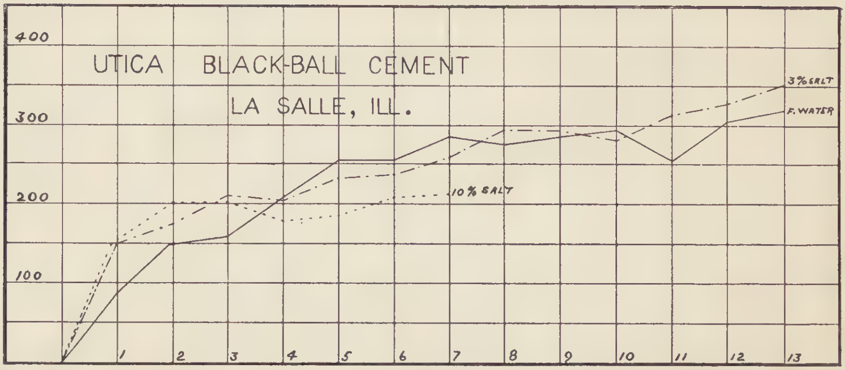
The gain also seems to be greater and more permanent with the Portland than with the natural cements.

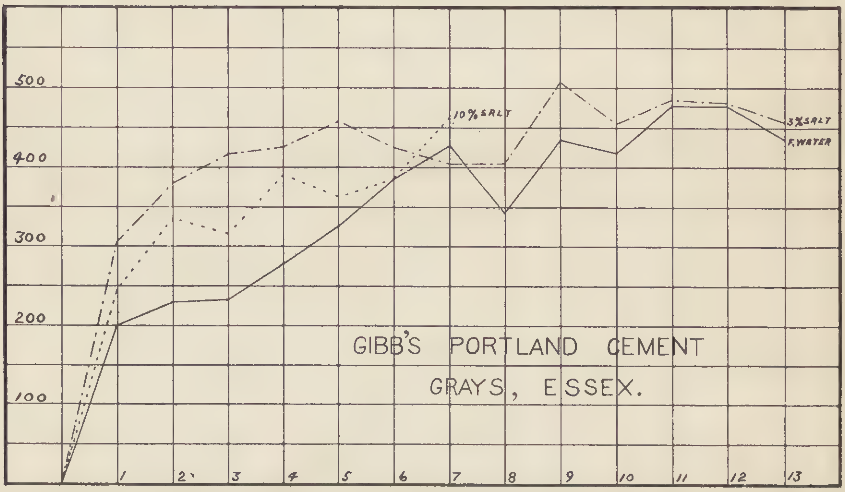
The effects of using a 10 per cent. seem not so good as with a 3 per cent. solution. The tests were not carried out for the

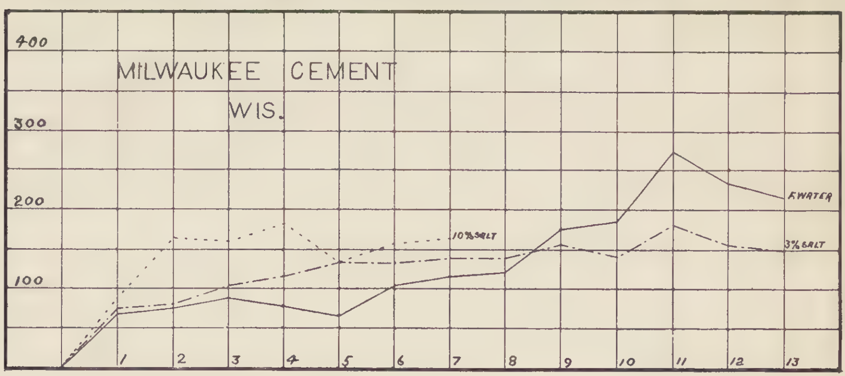
full thirteen weeks, and cannot be directly compared. The preceding tables give the average breaking strains of natural and Portland cements, with fresh and salt water, and the per cent. of average gain of salt over fresh water.

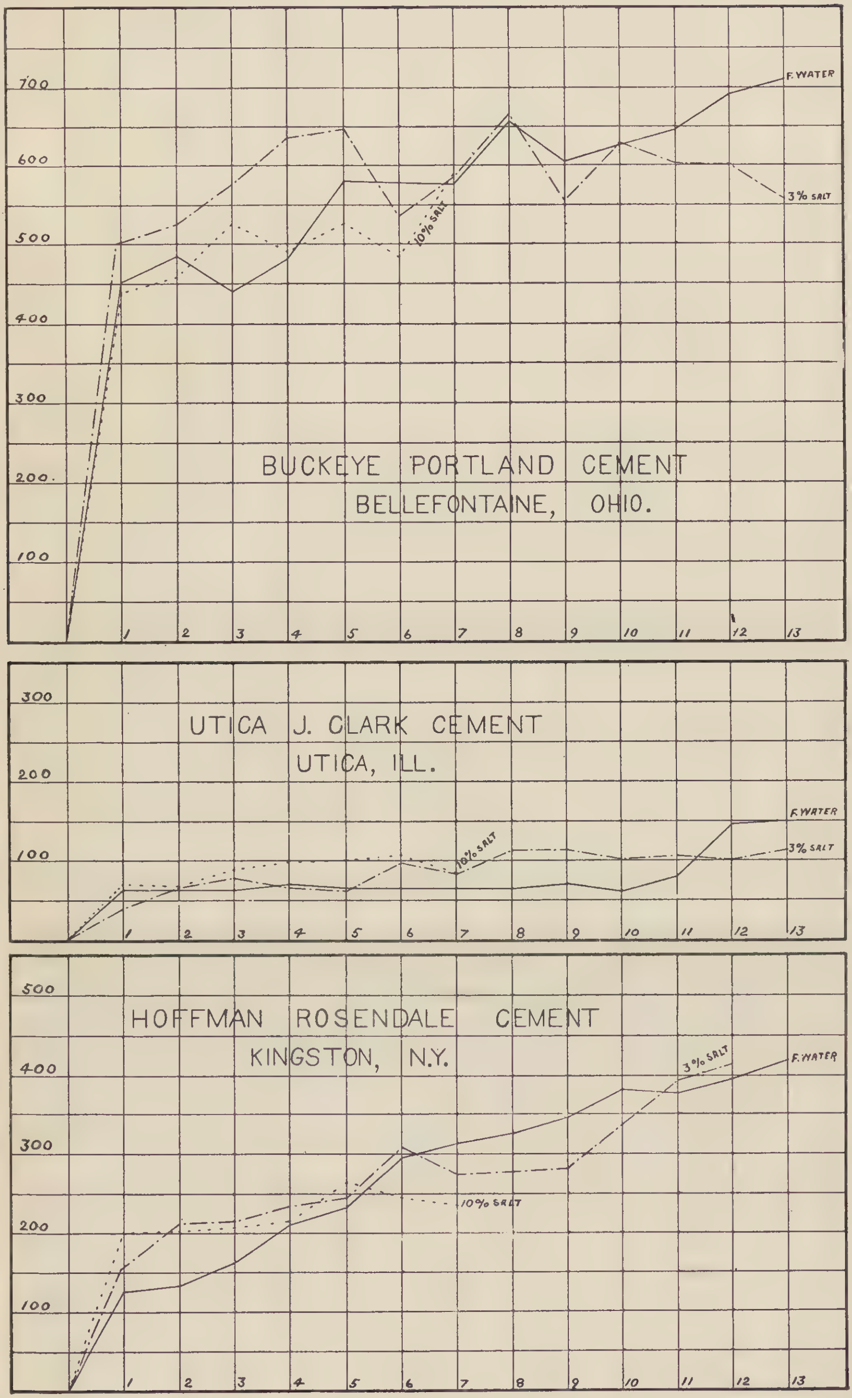
With those of fresh and salt water, the relative strength for the seven weeks tested can be seen from the tables and diagrams.

Valuable results might, no doubt, be obtained by a study of the chemical analysis of the different brands of cement in connection with the effect of salt water upon the same.


UTICA BLACK-BALL CEMENT
LA SALLE, ILL.
400
300
200
100
1 2 3 4 5 6 7 8 9 10 11 12 13
3% SALT
F. WATER
10% SALT


GIBB'S PORTLAND CEMENT
GRAYS, ESSEX.
500
400
300
200
100
1 2 3 4 5 6 7 8 9 10 11 12 13
10% SALT
3% SALT
F. WATER


MILWAUKEE CEMENT
WIS.
400
300
200
100
1 2 3 4 5 6 7 8 9 10 11 12 13
F. WATER
3% SALT
10% SALT



BUCKEYE PORTLAND CEMENT
BELLEFONTAINE, OHIO.
F. WATER
3% SALT
10% SALT
700
600
500
400
300
200.
100
1 2 3 4 5 6 7 8 9 10 11 12 13
UTICA J. CLARK CEMENT
UTICA, ILL.
F. WATER
3% SALT
10% SALT
300
200
100
1 2 3 4 5 6 7 8 9 10 11 12 13
HOFFMAN ROSENDALE CEMENT
KINGSTON, N.Y.
3% SALT
F. WATER
10% SALT
500
400
300
200
100
1 2 3 4 5 6 7 8 9 10 11 12 13

No. 3.

Hot Tests of Cement—Abstract from the Graduating Thesis of Frank Woolston, '94, Engineering Department, State University of Iowa.

The cements used in making these tests were purchased on the Chicago market by Musser & Co., of Iowa City. No mention was made at the time of purchasing that they were to be used for testing.

The briquettes were made in the Jameson Briquette Machine. The cement was used *neat* and *unsifted*, in the condition that it was taken from the barrel. As small amount of water as possible was used. The actual amount will be found in Table II. After being made, the briquettes were placed in galvanized iron pans and covered with a very damp cloth for twenty-four hours. At the end of twenty-four hours one-half the briquettes were placed in the hot water bath and the other half in a cold water bath. The water was changed every twenty-four hours. The hot water bath was kept at a constant temperature of 200° Fah. by means of a gas stove and a water jacket.

The briquettes were broken every twenty-four hours for one week, and then every week until a total of ninety days had expired from the time of immersion. Ten briquettes from the hot bath and ten from the cold bath were broken each time, and the breaking strains shown in the diagram are the average of these ten.

A chemical analysis of Dyckerhoff, Germania, South Bend, Buckeye, and Louisville was made by Mr. Earl Durfee, a student in advanced chemistry. This work was done under the supervision of Dr. L. W. Andrews, Professor of Chemistry.*

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*The method of analysis is given in full in the thesis, but omitted here. The student is referred to the article by Dr. Andrews, page 91.

CHEMICAL ANALYSIS.

I.	Dyckerhoff, ...	German Portland.
II.	Germania, ...	German Portland.
III.	South Bend, ...	American Portland.
IV.	Buckeye, ...	American Portland.
V.	Louisville, ...	American Natural.

	I	II	III	IV	V
Sil., . . .	20.25	22.36	19.26	20.80	18.92
Cal. ox., . .	58.03	64.38	60.25	57.82	46.90
Fr. ox., . .	4.03	4.15	3.39	4.64	1.91
Al. ox., . .	12.39	2.83	14.54	12.31	11.02
Mg. ox., . .	.74	1.87	Trace	4.84	.97

By an examination of the analyses, we find that III. has an excess of free lime and aluminum oxide. The free lime is plainly visible in the shape of large white specks. This cement cracked badly in setting when in the "hot test" room of the laboratory, which had a very moist temperature of about 80° Fah.

By placing the briquettes of this cement in a cool, dry place it set in twenty-four hours so that four briquettes attained the following breaking strength in twenty-four hours without signs of cracking: 147, 172, 98, and 115 pounds.

The briquettes immersed in the cold water bath showed signs of cracking in twenty-four hours, and in three weeks' time went to pieces, after having swelled to one and one-half their original size. The briquettes placed in hot water went to pieces entirely in one hour.

The barrel with what cement remained in it was then moved into the "hot test" room; temperature, 80°, and very moist. The cement soon swelled until the hoops were broken.

The first setting of this cement was so rapid that it was with difficulty the briquettes were made. No. IV. seemed to be the reverse of No. III. It was found to be almost impossible to make briquettes with it on account of its almost total lack of cementitious qualities. Some of it was mixed with water

and placed on a glass plate. It simply dried out without showing any cementing qualities.

Briquettes, after twenty-four hours under a damp cloth, were placed in a dry, cool room; temperature, 65° Fah. Could be easily crushed by the hand at the end of two weeks. Some that was used neat, as plaster in the laboratory, had about the consistency of sand at the end of three weeks.

This cement is shown to have had an excess of magnesium oxide, and a slight excess of ferric oxide, with a specific gravity lower than the other Portland cements. Both companies were notified of the results.

Diagrams.—In the diagrams, the *dotted* lines show the results of the "*cold water*" tests, and the *full* line the results of the "*hot water*" tests.

By reference to these diagrams, we find that with the best Portland cements tested, such as I. and II., there is but little difference between the "hot" and "cold" tests, as the two lines cross and recross. This would show that the effect of the "hot" test was very slight upon either of these cements.

In the case of II. the earlier strength of the "hot" tests was even less than in the "cold" and at seventy-six days the strength of the "hot" tests exceed that of the "cold" tests.

In I. the "hot" test is the weaker at the end of two weeks but at sixty-two days nearly equals the maximum reached by the "cold" test.

The Mankato cement (natural) shows an even, uniform increase. The "hot" rising somewhat faster at first but the "cold" steadily increasing until at the end of ninety days the two lines are but a few pounds apart.

At two weeks the Mankato briquettes showed slight checks but the strength was not effected and the checks did not increase.

Louisville (V.) shows a much more marked difference, the "hot" increasing rapidly in strength during the earlier stages. The "cold" show a uniform increase and the two lines would probably have crossed had the time been extended. At the end of seven days the "hot" test showed the same strength as the "cold" at the end of seven weeks.

The Milwaukee cement (natural) exhibits a marked difference of behavior in the two tests. In the "hot" test the strength increases rapidly during the earlier stages and then decreases until at the end of six weeks the briquettes are so weak as to make it impossible to test them, although at the end of ninety-seven days they are still intact. The increase in size is very marked. The briquettes in cold water gradually and continuously increase in strength.

In the mixing of the briquettes of the Milwaukee cement an excess of water was used, and it is to be regretted that the cement was not analyzed in order to ascertain if any of its constitutents could account for its failure under the "hot" test at such a late day.

Conclusions.—We find that the cements that show the best results under the "cold" tests, give practically the same results under the "hot" tests; there being no marked difference between the two lines at any time. Numbers I. and II. show very little differences and these differences constantly changing.

The strength of the natural cements is very much hastened during the earlier stages by the "hot" test but there is a gradual increase in the "cold" test that sooner or later makes the lines cross.

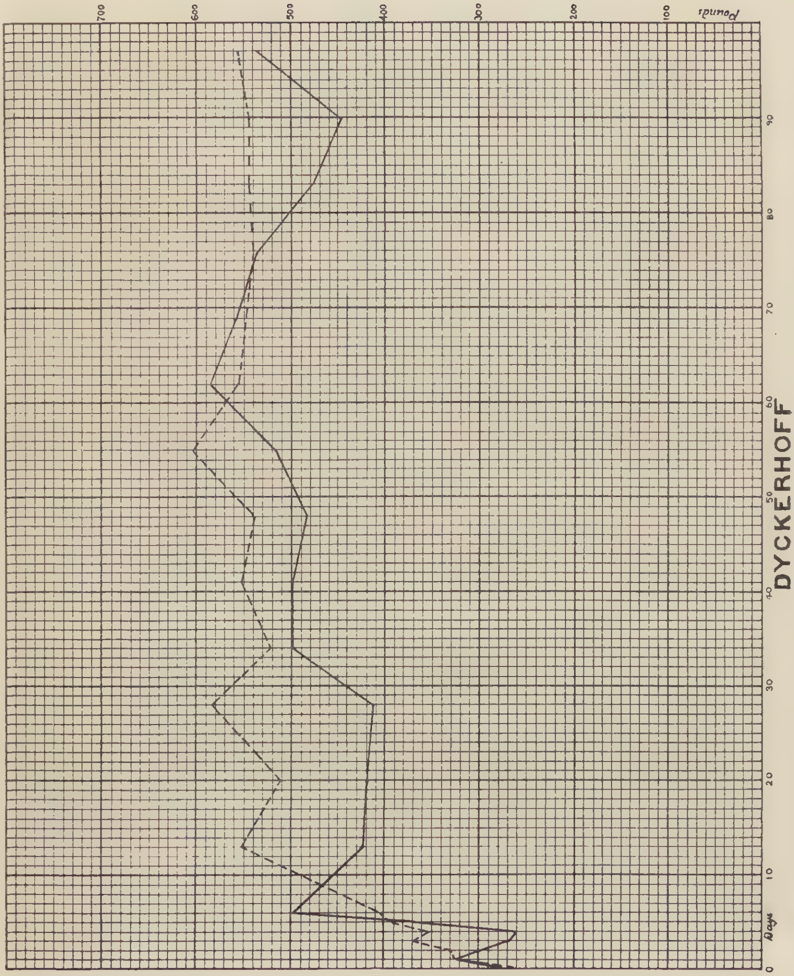
Some exceedingly faulty cements are exposed at once by the "hot" test as some of those, that were tested, were reduced to a lifeless powder after one hour in the hot water, and these same cements stood the ordinary twenty-eight day test well.

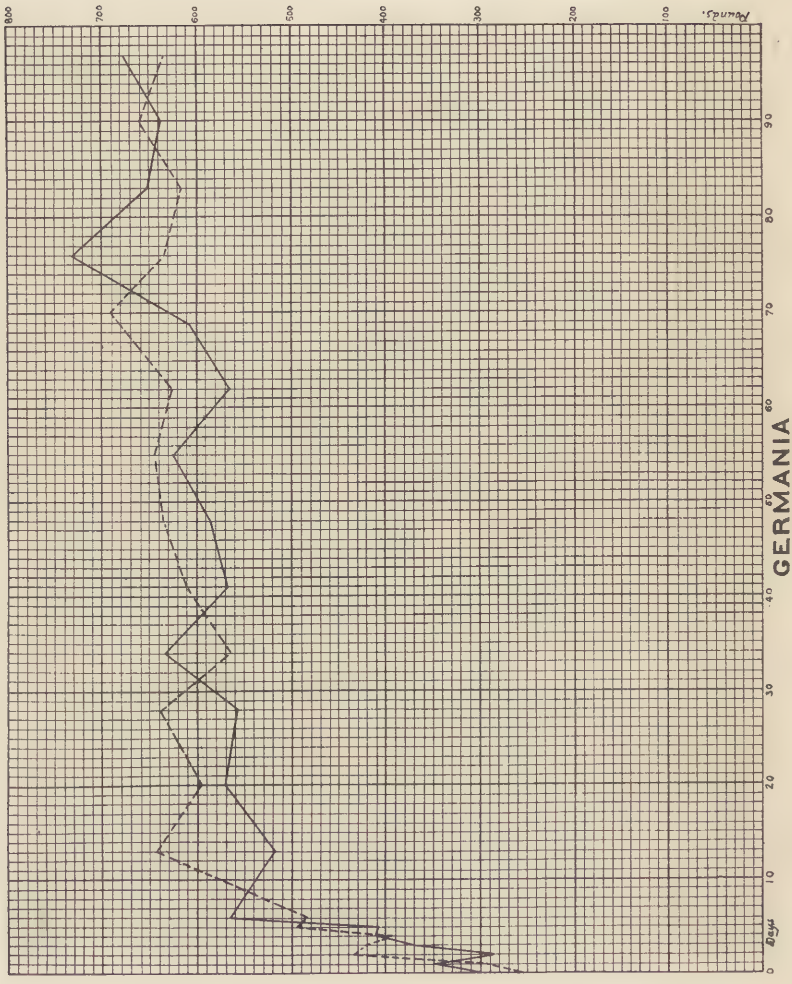
From the results obtained we may infer that no thoroughly good cement need fear the "hot" test. The strength of the briquettes may not reach the maximum of those reached by the "cold" tests but they will approximate them.

Cements that contain an excess of free lime will not stand the "hot" tests, and when but a limited time is possible for the testing the "hot" test has every advantage over the "cold." In the case of the Louisville and the Milwaukee results were reached in one week by the "hot" test that exceeded those reached by the "cold" tests in over seven weeks.

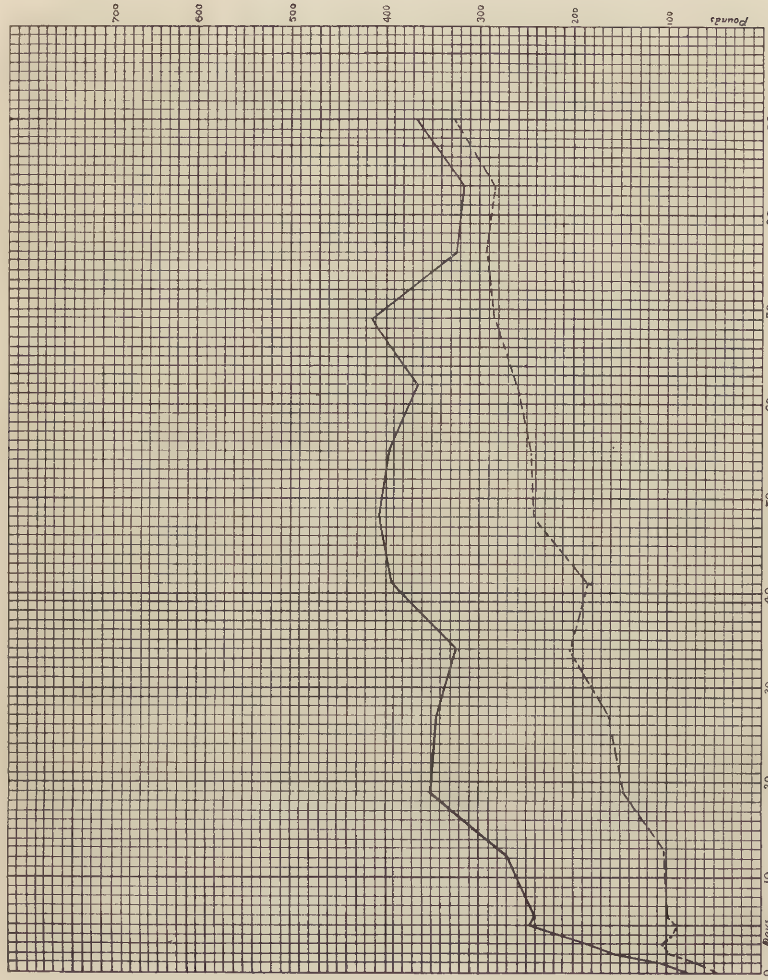
TABLE II.

Cement.	Per cent. fineness 100 mesh sieve.	Cu. cent. water per lb. cement.	Remarks.
Dyckerhoff.	91.8	120	Residue dark, sharp, and heavy.
Germania ..	90.6	140	" light colored, soft and light.
Milwaukee .	79.7	162	" " " sharp, and coarse.
Louisville..	72.8	190	" color as cement, sharp, coarse, heavy.
Mankato ...	76.7	156	" medium weight with dark specks.
South Bend.	91.7	118	" dark, sharp, heavy, with white specks.
Buckeye ...	84.6		" soft, light, and fine.

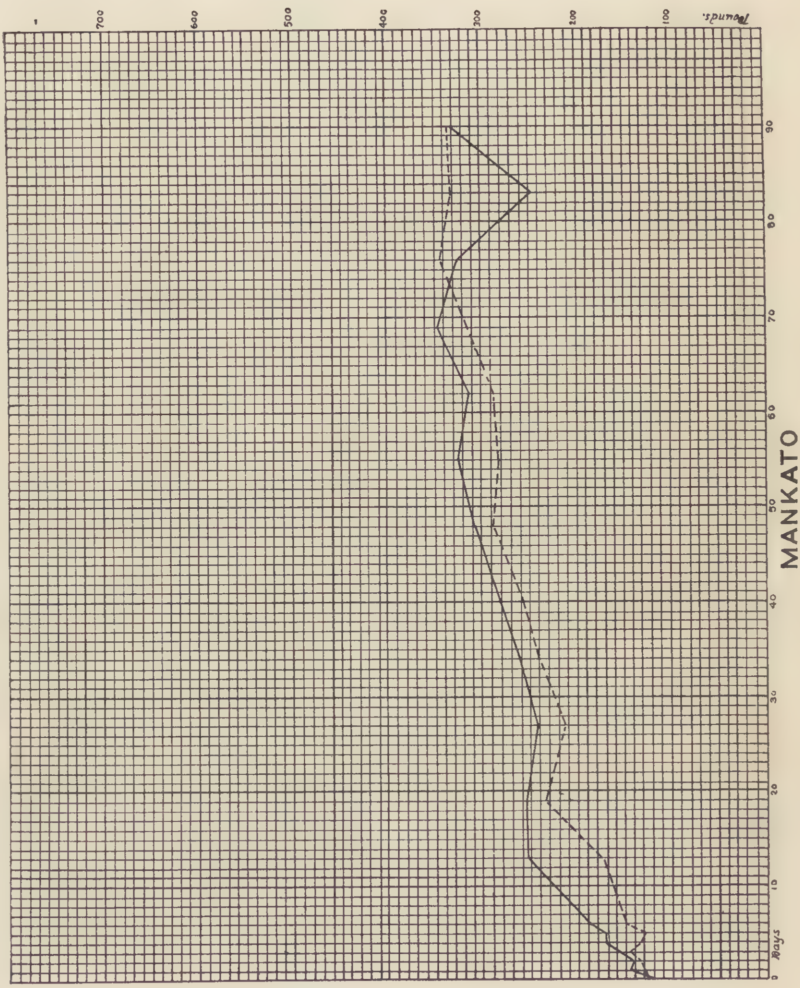

Pounds
100
200
300
400
500
600
700
Days
0
10
20
30
40
50
60
70
80
90
DYCKERHOFF

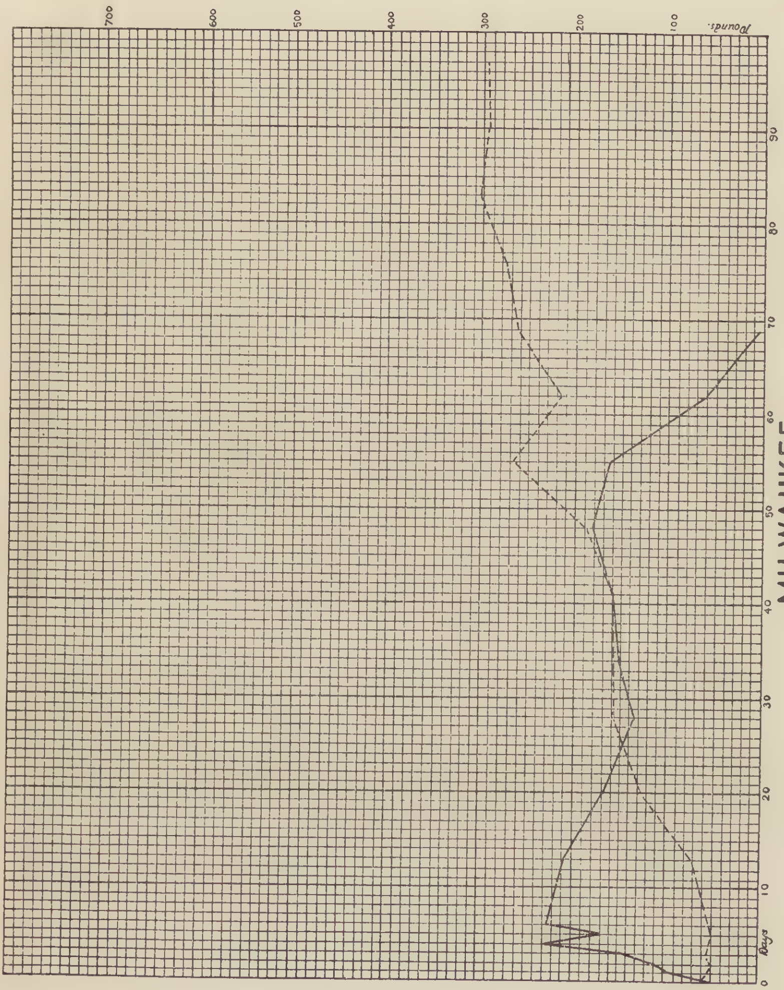


800
700
600
500
400
300
200
100
Pounds.
Days
0
10
20
30
40
50
60
70
80
90
GERMANIA


Pounds
100
200
300
400
500
600
700
Days
0
10
20
30
40
50
60
70
80
90

LOUISVILLE


Pounds.
100
200
300
400
500
600
700
Days
0
10
20
30
40
50
60
70
80
90
MANKATO


Pounds.
100
200
300
400
500
600
700
Days
0
10
20
30
40
50
60
70
80
90

MILWAUKEE

INDEX.

Date Due
